PHYTOTOXICOLOGY ASSESSMENT SURVEYS IN THE VICINITY OF BURNSTEIN CASTINGS, ST. CATHARINES MARCH 1988 THROUGH FEBRUARY 1990

JULY 1992

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Report prepared by:

Phytotoxicology Section
Air Resources Branch
Ontario Ministry of the Environment

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Phytotoxicology Assessment Surveys Conducted In the Vicinity of Burnstein Castings, Catherine Street, St.Catharines - March 1988 through February 1990.

INTRODUCTION

During 1988 and 1989, soil and vegetation collection surveys were conducted by the Phytotoxicology Section in the vicinity of Burnstein Castings, Catherine Street, St. Catharines. Also, during 1989, soil from the area was collected for plant/soil bioassay studies at the Section's greenhouse in Brampton. Burnstein Castings, formerly called Samco (1966-1970), has operated at the present location since 1966. The company leases the property from the City of St. Catharines. The surveys were requested by MOE staff, Welland office, as area residents were concerned that emissions of metals (e.g. lead) from the Burnstein Castings plant may be contaminating area properties. The 1988 soil and tree foliage results, which have been previously reported (see ARB-085-88-Phyto and ARB-176-88-Phyto), indicated that the company is a source of primarily copper emissions. This report presents the results of the more recent field surveys in 1989 as well as the results of the greenhouse soil/plant bioassay experiments which were conducted by phytotoxicology staff through to February 1990. The 1988 soil and foliage data also are included.

SAMPLING PROGRAMS

Soil Collections In 1988 & 1989

On March 3, 1988, a preliminary soil collection survey was conducted in the vicinity of the Burnstein Castings plant in St. Catharines. Additional soil sampling was conducted in May 1988, May 1989 and August 1989. The May 1989 sampling

program was of much larger scale than the others surveys, with soil sampling being conducted on numerous residential properties throughout the general area, particularly to the neighbouring west, north and northeast of the company. Surface soil also was sampled during 1988 and 1989 from public properties in the general area of the Burnstein plant, including the elementary school playfield (Site 1) to the west, the community center property (Site 5) to the north, the senior' residence property (Site 4) to the northeast, the park (Site 3) to the east, and boulevards off residential properties. During March 1988 through August 1989, soil for analysis was collected from a total of 165 sites (77 locations) on residential (139 sites) and public (26 sites) properties in the vicinity of Burnstein Castings (see Table 1 and Figure 1).

Common sampling sites on residential properties were boulevards, front and/or back lawns, flower or shrub beds, and gardens. At publicly accessible sites (school/park playfields, boulevards) primarily non disturbed lawn areas were sampled. Surface soil at lawn sites, including boulevards, was sampled to the standard 5 cm depth except during the initial survey in 1988. In March 1988, only shallow soil cores to about a 2 cm depth could be collected because of frozen soil conditions at all sampling sites. At disturbed sites (bedding areas, gardens), soil was sampled to the usual tilling depth of 15 cm. In addition to surface soil sampling, subsoil was collected from 13 sites at one or more depths (usually 15-20 cm or 10-15 cm) to assess the extent of contamination in the soil profile. At Site 75, found to be the most contaminated site, subsoil for analysis was sampled to a 55 cm depth. Duplicate samples normally were collected except in cases where subsoil (one sample per site) was collected. Lawn or grass covered sites were sampled with an Oakfield soil sampler, while bedding areas and gardens were usually sampled with a small hand shovel, using standard sampling procedures.

<u>Soil Collected for Greenhouse Studies</u>

Also, during 1989, soil from the general area of the Burnstein plant was collected in June and August and returned to the Phytotoxicology Section Controlled Environment

Unit at Brampton for plant/soil bioassay studies. In June, surface soil (0-5 cm) was collected from the boulevard at Sites 30, 67, 75, 77 and 78 (see Figure 1) and, in August, additional surface soil as well as subsoil was collected at Site 75. Grass or lawn growth appeared normal at all sites except in the general area of Site 75 where grass growth was generally sparse or absent.

Foliage Collections in 1988 and 1989

In order to assess the status of current, ongoing emissions from Burnstein Castings, maple foliage collection surveys were conducted in late August of 1988 and 1989. Each year, maple foliage was collected from the exposed side of seven locations (Sites 1, 2, 3, 4, 5, 6 and 7) in the immediate vicinity of the Burnstein plant as well as at five more remote locations (Sites 8, 9, 10, 11 and 12). As with soil, duplicate samples were collected at each site (see attached Figure 3). The foliage collected from Sites 3 and 4, which were adjacent to the windows along the west side of the Burnstein Castings building, displayed a fine blackish surface deposition in both years. The foliar deposition observed at these sites in 1989 appeared reduced from 1988 levels. At the time of foliage collection in 1989, the windows along the building's west side previously had been blocked closed from the northwest corner (Site 3 area) through to the general area of Site 4, where closure of the window openings with cement blocks was still underway. In 1988, the windows were open. Also, in both years, Sites 3 and 4 displayed leaves with marginal brownish-black necrosis. Similar injury was observed on mature maples inspected over the larger area in August 1989.

Vegetable Collections in 1989

Also, in late August 1989, vegetable crops were sampled in the immediate area of the Burnstein plant. In the garden at soil collection Site 28 (Pleasant Ave.), beet foliage and roots, Swiss chard foliage and tomatoes were collected. Also, beet foliage and roots, carrot foliage and roots, and cucumbers were sampled in the large garden at Site 35 (Russell Ave.), situated to the neighbouring west of the company. In addition, tomatoes were sampled in the garden at soil Site 19 (Russell Ave.), to the north. As

well, corresponding vegetable crops, excluding cucumber, were sampled in rural gardens well remote from the Burnstein Castings plant in late August 1989. Moreover, in early December 1989, kale produce from the Site 68a property (Woodland St), to the east of the company, was collected for analysis at the request of the property owner. Kale produce (control samples) also was collected from a local supermarket, with duplicate Kale samples being collected at each location. With the other crops, single samples normally were collected for analysis.

SUBMISSION OF SAMPLES FOR ANALYSIS

The samples collected for chemical analysis were delivered to the Phytotoxicology Section for processing. The maple foliage samples were left unwashed while the vegetable samples were processed on a washed "as consumed" basis. All samples were dried, ground and stored in glass bottles, including the soil samples which were seived to 0.35 mm particle size. Then, they were submitted to the MOE Laboratory Services Branch for analysis. The soil and vegetation samples were analyzed for copper (Cu), as well as cadmium (Cd), chromium (Cr), cobalt (Co), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), vanadium (V) and zinc (Zn). Samples also were submitted in 1988 and/or 1989 for analysis of aluminum (Al), beryllium (Be), sodium (Na) and strontium (Sr) in cases where a result is shown on the attached tables.

EXPLANATION OF UPPER LIMIT OF NORMAL GUIDELINES

In this report, the soil and tree foliage results are compared with Phytotoxicology Section "Upper Limit of Normal" (ULN) guidelines for urban areas. Each ULN was determined by examining an extensive database for soils and vegetation samples collected at sites removed from any point source of contamination. Statistical tests were applied to the data to calculate the ULN value. This ULN value would not normally be exceeded in 99 samples in 100 for background areas. Values which exceed the ULN are considered likely to have resulted from contamination. Values which exceed the ULN do not necessarily imply that the element is toxic at that level.

ANALYTICAL RESULTS

Results for Soil Collections

The metal results for all soil samples collected during March 1988 through August 1989 are summarized and compared to the Phytotoxicology Section ULN guidelines in attached Table 1. ULN urban guidelines have been developed by the Phytotoxicology Section for all sixteen elements except aluminum, beryllium, magnesium, sodium and strontium. In these cases, the results were compared to levels found at sites more remote from the Burnstein plant.

Concentrations of Copper in Soil

Table 1 shows that several sites in the immediate area of Burnstein Castings have a copper concentration in surface soil exceeding the respective 100 ppm ULN guideline. About half the total number of sampling sites (78/165) had a soil copper level of 100 ppm or higher. Boulevard Sites 30, 73, 74, 75, 76 & 77 and the front lawn at Site 18 had the highest soil copper concentrations ranging from 1000 to 10000 ppm, with all other lawn sites having less than 1000 ppm. The two highest levels were detected at Sites 75 (10000 ppm) and 76 (2400 ppm) on the public boulevard immediately adjacent to the west side of the Burnstein Castings plant. The next highest level of 1800 ppm (Site 30) was found on the boulevard on the opposite east side of George Street (see Figure 1). Flower/shrub beds (16 total) sampled throughout the survey area contained soil copper levels in the 26 to 270 ppm range, with the bedding soil at five locations (Sites 30, 53, 58c 60 and 63) having greater than 100 ppm copper. Backyard gardens (11 total) had between 20 to 160 ppm copper, with only the garden soils at Site 19 (160 & 150 ppm) having more than 100 ppm copper.

The fact that soil copper levels were elevated at several sites in the immediate area of Burnstein Castings, with generally lower levels being found at more remote sites, implicates emissions from Burnstein Castings as the primary source of the Cu elevation in the surface soil. The surface soil (0-5 cm) data obtained in 1988 and 1989 were used to construct a computer-generated 100 ppm copper contour so as to

delineate the area with above-normal (>100 ppm) copper concentrations in surface soil. This contour is shown on attached Figure 2. This contour shows that the area with copper levels of 100 ppm or higher in surface soil (0-5 cm) extends outward from the Burnstein Castings plant through to about 200 m northeast (downwind) of the company's north boundary.

All sites where subsoil was collected revealed a pattern of higher Cu levels in the surface soil (0-2 cm and/or 0-5 cm), further implicating the presence of an atmospheric source of Cu deposition in the area. All sites where subsoil was collected had under 100 ppm copper, except Sites 5a (520 ppm) and 73 (280 ppm) at a depth of 10-15 cm, and Site 75 (120 cm) at a 15-20 cm depth. It is suspected that the elevated copper level in the subsoil at Site 5a had resulted from soil excavation or other site disturbance activities during construction of the fairly new community center building.

In August 1989, the MOE's Hazardous Contaminants Co-ordination Branch (HCCB), at the request of the West Central Region, conducted a review of the potential human health implications of the copper levels in soil in the vicinity of the Burnstein Castings plant (see Appendix 2). The relative contribution of soil/dust ingestion to total copper exposure of adults and children was assessed against rough estimates of intakes from the air, drinking water and food pathways. The estimated human intake values for even the worst case soil level of 10000 ppm copper (Site 75) were found to be below or within the range of acceptable intake, which implicates no health concern.

Concentrations of Other Metals In Soil

The surface soil from boulevard Site 75 also was found to have concentrations of lead (575 ppm), nickel (75 ppm), and zinc (825 ppm) exceeding the respective ULN guidelines (500, 60 and 500 ppm). The 500 ppm guideline for zinc also was slightly exceeded at nearby Site 76 (540 ppm), which was closer to the northwest corner of the Burnstein building. At all other sites, including bedding areas and gardens, soil levels of lead, nickel and zinc did not exceed the ULN guidelines (see Table 1).

Soil concentrations of cadmium, chromium, cobalt, iron, manganese, molybdenum, and vanadium at sites closest to the company, although in some cases slightly above levels detected at more remote sites, revealed no marked elevation as compared to the ULN guidelines. Of these elements, only the highest levels of chromium (51 ppm at Site 13, not in the immediate area of the company) and manganese (720 ppm in subsoil (15-20 cm) at Site 4) were marginally in excess of the respective 50 and 700 ppm ULN guidelines.

The higher soil levels of aluminum (10000-12000 ppm), beryllium (1.7-2.5 ppm), magnesium (12000-15500 ppm), sodium (195-225 ppm) and strontium (35-52 ppm) found at lawn sites in the immediate area of the Burnstein plant were similar to the higher soil levels of aluminum (7000-11500 ppm), beryllium (1.0-1.5), magnesium (7800-10750 ppm), sodium (205-220 ppm) and strontium (24-32 ppm) found at more remote sites. ULN urban guidelines for these elements have not been developed.

Results for Foliage Collections

The August foliar results for both years are presented in attached Table 2. In 1988, foliage Sites 3 and 4, situated on the boulevard adjacent to the west side of the Burnstein Castings plant, contained levels of copper (52 & 25 ppm), molybdenum (2.1 & 2.8 ppm) and nickel (12 ppm) exceeding the respective ULN guidelines (20, 1.5, and 5 ppm). In 1989, foliar levels of these metals throughout the survey area generally were reduced from 1988 levels, with only the ULN guideline for copper (20 ppm) being exceeded at the same sites - Sites 3 (28 ppm) and 4 (26 ppm). In both years, foliage sites more remote from Burnstein Castings contained generally lower levels of these elements, indicating that Burnstein Castings was an emitter during the 1988 and 1989 growing season. However, the elevated foliar levels of copper, molybdenum and nickel in 1988, and of copper in 1989, were confined to the immediate area of the Burnstein building, suggesting that current operations at the Burnstein plant are not resulting in widespread contamination. The foliage results, together with the soil data, suggest that operations at Burnstein Castings, over the

years, have been a more significant emission source of copper than of the other metals and that historic emissions/activities (as opposed to current emissions/activities) have been the major contributor to the elevated soil copper levels found in the survey area.

Slightly higher foliar levels of chromium, cobalt, iron, lead, manganese, vanadium and zinc also were detected in 1988 and/or 1989 at some sites in the immediate area of Burnstein Castings compared to more distant sites, suggesting that the company also is a potential emitter of these elements (Table 2). However, as the higher levels were only very marginally elevated compared to those at more remote locations and as none were in excess of the respective ULN guidelines, it would appear that current operations at the Burnstein Castings plant are not a significant emission source of these metals. As with copper, molybdenum and nickel, foliar levels of other metals at sites close to Burnstein Castings also were generally lower in 1989 than in 1988. These results, coupled with foliar deposition and rainfall being reduced in 1989 from 1988 (see Table 4), would indicate that ambient metal emissions from the company likely were reduced in 1989. These results also implicate historic emissions/activities as the primary contributor to the elevated soil levels of lead, nickel and zinc which were found on the adjacent boulevard west of the company.

The preceding foliar results, together with the observations and the weather data (Table 4), would suggest that the foliar injury (necrotic tips/marginal browning) observed on mature maple trees throughout the survey area in late August 1989 was more likely related to droughty weather conditions than to emissions from the Burnstein Castings plant. Similar foliar injury was observed in the survey area in August 1988.

Results for Vegetable Collections

In attached Table 3, the metal concentrations detected in the washed vegetable samples collected in the urban gardens near the Burnstein Castings plant are

compared to the corresponding levels found in rural gardens well remote from the company. It is apparent that levels of copper in all urban samples were similar to those found in the remote rural vegetables. Levels of other elements, in most cases, also were not markedly different from remote levels. Table 3 shows that lead levels were slightly higher in the urban beet and carrot foliage (1.2-2.5 ppm), with levels in the corresponding beet and carrot roots (<0.5 ppm), which are more commonly eaten, being below the analytical detection limit (0.5 ppm). A brief review of the literature indicated that lead levels up to 3 ppm are not abnormal in vegetable crops and the Kale data further support this claim.

In the case of copper, Swiss chard foliage was found to have the highest copper level of 10 ppm. This level was well below the estimated worst-case level of 140 ppm used in the MOE HCCB health risk assessment study, which implicated no health concern. As the level of 140 ppm is an estimated worst case level for unwashed vegetables (vegetables collected in the Burnstein area were washed before analysis), the exposure assessment model is conservative. Hence, based on the preceding information, there would not appear to be any human health threat from consuming vegetables (washed beforehand) grown in the area of the Burnstein plant.

RESULTS OF GREENHOUSE STUDIES

The greenhouse soil/plant growth bioassay studies and results are discussed in detail in Appendix 1 attached. The primary objective of these studies was to determine soil copper levels potentially deleterious to plant growth, using common garden vegetables (bean, radish, spinach) as indicators. A brief review of the literature suggested that vegetable crops are fairly sensitive to elevated copper levels in soil. Analysis of the surface soils used in the bioassay studies revealed a slight variation in soil copper levels from the original levels already noted in the report, which would be expected because of natural variation. For example, the surface soil collected at Sites 75 and 77 initially was found to have copper levels of 10000 and 1150 ppm respectively, with the corresponding mixed potted soil for the bioassay work having slightly higher levels

of 11405 and 1511 ppm.

In bioassay #1, the soils with the highest total copper levels of 6483 and 11405 were found to cause severe chlorosis and stunting of the roots and shoots in both radishes and beans, with no apparent damage at copper concentrations of 1852 or less. The results of Bioassay #2 revealed that the threshold for plant damage due to copper toxicity was between 1333 and 2233 ppm for both the fertilized radish and spinach plants. Bean root systems were adversely affected by soil copper levels of greater than 2233 ppm.

Based on the radish studies, the highest copper levels found in roots (excluding the anomolous 150 ppm level) was 26 ppm and in foliage was 89 ppm (respective soil concentration was 1333 ppm). These tissue levels also were below the estimated worst-case level of 140 ppm, used in the MOE health risk assessment study. The fact that the residential garden soils sampled near Burnstein Castings had copper levels of only 20-160 ppm, and that copper levels in the vegetables (washed) collected in the Burnstein area were low, further indicates that there is no health risk in eating vegetables from the area of Burnstein Castings.

SIGNIFICANCE OF SOIL METAL LEVELS FROM A PLANT INJURY AND HUMAN HEALTH PERSPECTIVE

Significance of Copper

The bioassay studies on surface soils from the area of Burnstein Castings indicated that the threshold for copper toxicity to sensitive vegetation (vegetable plants) lies between 1333 and 2233 ppm in the soil. Copper toxicity was not confirmed at lower soil concentrations down to, and less than, the MOE's 300 ppm clean-up guideline (based on phytotoxic levels reported in the literature) for decommissioning contaminated industrial properties, likely because of a near or above neutral soil pH. Adverse injury to vegetation on residential properties would not be expected as the soil copper concentrations that were found in front and back lawns (19-1000 ppm),

bedding areas (26-270 ppm) and gardens (20-160 ppm) were below even the lower limit of the range for potential toxicity (1333-2233 ppm).

Between March 1988 and August 1989, six City-controlled boulevard sites in the immediate area of Burnstein Castings (Sites 30, 73, 74, 75 & 76 to the west; and Site 77 to the east), were found to have a copper concentration above the lower limit of the injury range. Sites 75 (10000 ppm) and 76 (2400 ppm) had the highest levels and greatest potential for phytotoxicity. The boulevards were landscaped with mature trees and grass. Shallow-rooted vegetation, such as grass, would be expected to have a greater potential for injury than mature trees. However, grasses are known to be fairly tolerant of elevated metal levels in soil, and grass growth appeared normal on boulevards with up to 1800 ppm copper. Copper concentrations in excess of 1800 ppm were found only at boulevard Sites 75 and 76, beside the northwest corner of the Burnstein building. In this area, grass growth in areas generally was poor, an indication that the excessive copper levels in the surface soil may be involved. With the highest copper concentrations being confined to the surface soil (0-5 cm), deep-rooted trees would not likely be adversely affected. On the basis of the MOE health risk assessment study, none of the soil copper levels that were found would be expected to pose a threat to human health.

Significance of Lead, Nickel and Zinc

The lead concentration in the surface soil (575 ppm) at Site 75 is marginally above the MOE's 500 ppm clean-up guideline (residential) and is a potential health concern as the clean-up guideline is based on human health. The concentration of zinc at Site 75 (825 ppm) also is marginally above the clean-up guideline (800 ppm, based on phytotoxicity) and is potentially phytotoxic. In contrast, the elevated soil concentrations of nickel at Site 75 (75 ppm), and of zinc at Site 76 (540 ppm), were below the respective soil clean-up guidelines (200 & 800 ppm) and would not be expected to be a threat to the health of plants or humans.

SUMMARY

Between March 1988 and August 1989, soil copper levels exceeding the Ministry's ULN urban guideline of 100 ppm were detected at 78 (of 165 total) sites throughout an area which extended outward from the Burnstein Castings plant to a maximum distance of about 200 m northeast (downwind) of the company's north boundary. Sites 75 (10000 ppm) and 76 (2400 ppm) on the boulevard just west of the Burnstein building northwest corner had the highest copper levels in surface soil (0-5 cm), with levels in subsoil being substantively lower. Soil levels of lead (575 ppm), nickel (75 ppm) and zinc (825 ppm) at Site 75, and of zinc (540 ppm) at Site 76, also marginally exceeded the ULN guidelines. Lead and zinc concentrations at Site 75 also exceeded the respective MOE soil clean-up guidelines (500 & 800 ppm) applied to decommissioning sites. Foliage Sites 3 and 4, on the same boulevard, displayed slight to moderate elevation of copper, molybdenum and nickel in 1988, and marginally elevated copper levels in 1989, relative to the ULNs. Because the foliar data indicated that current operations at Burnstein Castings represent only a minor emission source of metals, including copper, it is concluded that historic emissions from Burnstein Castings (and/or Samco) have been the major contributor to the elevated soil levels of copper and other metals found in the immediate area of the company.

A total of six boulevard sites (Sites 30, 73, 74, 75, 76 & 77), all situated in the immediate area of the company, were found to have a soil copper concentration within or above the plant injury range (1333-2233 ppm) determined from the greenhouse bioassay experiments. Grass growth appeared normal at these sites except on the boulevard (Sites 75 & 76) beside the northwest corner of the Burnstein building. In this area, grass growth in areas appeared poor , an indication that the excessive copper concentrations in the surface soil may be involved. Deep rooted trees on these boulevards will not likely be adversely affected, with the highest copper concentrations being confined to the surface soil. As City-controlled boulevards were affected, it is recommended that the City of St Catharines be informed. On residential properties, soil copper levels in front and back lawns, gardens and bedding areas

were below even the lower limit of the range for potential injury (1333-2233 ppm); hence, the surface soil copper levels on residential properties would not be expected to adversely affect plant growth.

Finally, on the basis of the MOE HCCB health risk assessment review, the elevated soil copper levels found in the survey area would not be expected to pose any human health threat to the community. The results of the MOE health risk review, together with the results of vegetable sampling on residential properties in the survey area in 1989, also did not suggest that there would be any threat to human health from consuming vegetables (washed) grown in the area of Burnstein Castings.

TABLE 1: SOIL METAL CONCENTRATIONS (PPM, DRY WT) * DETECTED IN THE VICINITY OF BURNSTEIN CASTINGS, CATHERINE ST., ST. CATHARINES - MARCH 1988 THROUGH AUGUST 1989

STREET	LOCATION FIG 1	SAMPLING SITE	Cu	Pb	Ni	Zn	Al	Be	Cd	Cr	Co	Fe	Mg	Mn	Mo	Na	Sr	V
RESIDENTIAL PROPERTIES																		
BRIGGER	58a	FRONT LAWN **	135	38	12	83	10000	0.8	<0.5	18	6	20000	2800	325	0.6	77	17	35
	58b	SIDE LAWN	470	84	16	140	9550	0.7	0.2	17	6	17000	4450	310	0.9	97	26	27
	58c	BED	260	105	18	130	8900	1.1	0.1	19	8	22500	6450	405	1.4	140	54	30
CATHERINE	24	BOULEVARD	38	160	11	120		<0.5	0.9	26	6	12000	10750	475	0.4			22
COLBEY	22	FRONT LAWN	62	94	12	110		0.6	0.7	18	7	15000	2050	300	0.3			29
DUFFERIN	26	BOULEVARD	60	102	14	103	8700	0.7	0.3	17	7	15000	4000	385	0.6	108	19	26
GEORGE	14	FRONT LAWN	47	255	14	155		0.6	0.8	20	8	13500	4000	530	0.4			23
GEORGE	9	BOULEVARD(0-2cm)	64	180	14	145			0.8	18	8	15000		555	<1			27
GEORGE	13	FRONT LAWN	45	305	12	210		0.6	1	40	7	13000	1900	345	<0.2			24
		BACK LAWN	45	170	12	195		<0.5	1	51	7	12500	1650	270	0.4			25
GEORGE	25	BOULEVARD	103	200	15	175	7050	0.8	0.6	16	6	15000	4300	315	0.9	67	16	28
GEORGE	12	FRONT LAWN	840	205	20	195		0.7	0.6	19	7	14500	2600	350	0.4			26
		(15-20CM)	64	190	13	79	9000	0.8	0.2	14	7	16000	2000	360	1.1	65	16	29
GEORGE	30	BOULEVARD	1800	250	36	410	6750	2.4	0.9	31	6	14500	10000	490	1.1	165	28	25
		FRONT LAWN	445	106	24	170	9350	0.8	0.3	26	7	16500	3350	335	1	110	20	29
		FRONT BED	210	128	18	205	9800	0.7	0.6	20	7	18000	4300	405	1	115	29	28
		BACK LAWN	270	165	15	140	7600	0.8	0.5	17	6	15000	3000	385	1	90	22	25
		BACK BEDS	120	139	14	125	7950	0.6	0.4	24	7	15500	3400	430	1.3	105	29	25
GEORGE	31	FRONT LAWN	160	83	16	110	8900	0.9	0.2	16	6	15500	4050	360	1.1	89	22	27
		BACK LAWN	81	70	13	93	9250	0.7	0.2	14	6	14500	2350	280	0.9	80	17	25
GEORGE	8	BOULEVARD	365	145	18	165		0.6	0.8	20	7	14000	6800	410	<0.2			25
		(0-2CM)	655	170	23	215			0.7	23	8	14000		430	<1			24
		(15-20CM)	34	48	10	53		0.8	0.5	16	7	14000	2900	400	<0.2			26
		BACK LAWN	55	115	13	145		0.8	0.7	20	8	14000	2450	320	<0.2			27
GEORGE	11	FRONT LAWN	165	115	15	125	8850	0.6	0.3	15	7	15000	2800	305	1.1	88	14	26
		FRONT BED	85	205	14	220	8700	0.8	0.3	15	8	15500	2150	340	1.2	87	14	27
		BACK LAWN	56	118	14	145	10150	0.9	0.3	18	7	16000	2250	315	1	76	17	29
		GARDEN	47	115	12	170		0.7	0.7	18	8	13000	2550	275	<0.2			24
GEORGE	10	FRONT LAWN	175	170	16	180		0.7	0.9	23	8	15000	2500	355	0.5			28
		BACK LAWN	41	100	12	140		0.7	0.9	19	8	15000	3300	315	<0.2			27

TABLE 1: SOIL METAL CONCENTRATIONS (PPM, DRY WT) * DETECTED IN THE VICINITY OF BURNSTEIN CASTINGS, CATHERINE ST., ST. CATHARINES - MARCH 1988 THROUGH AUGUST 1989

STREET	LOCATION FIG 1	SAMPLING SITE	Cu	Pb	Ni	Zn	Al	Be	Cd	Cr	Co	Fe	Mg	Mn	Mo	Na	Sr	V
GEORGE	52	BOULEVARD	495	245	25	235	8450	1	0.7	20	7	15500	9900	420	1	155	40	26
		FRONT LAWN	210	145	15	165	9400	0.6	0.6	16	6	15500	3000	355	0.5	74	18	26
		FRONT BED	90	150	13	195	9600	0.7	0.4	16	7	16500	2550	395	1.1	93	17	27
GEORGE	51	BOULEVARD	150	175	21	165	8850	0.9	0.6	18	8	16000	8000	400	1.2	180	52	25
		FRONT LAWN	160	225	18	165	9000	0.7	0.7	17	7	16000	5500	390	1.1	120	30	25
		BACK LAWN	160	170	16	180	9900	0.8	0.6	17	7	17000	3050	375	0.3	87	19	28
GEORGE	40	BOULEVARD	140	135	13	125	7650	0.7	0.3	16	6	15000	7050	445	0.7	130	22	25
		FRONT LAWN	75	125	13	115	8900	0.9	0.4	22	6	16000	3050	410	0.9	92	19	28
		FRONT BED	28	170	11	130	9200	<0.5	0.2	16	7	15000	2500	340	0.4	87	16	23
		BACK LAWN	38	80	12	100	8900	0.7	0.3	15	6	15000	2250	295	0.9	90	19	27
		BACK BED	34	75	11	105	8500	0.5	0.3	14	5	14000	1850	260	0.7	68	15	24
GEORGE	49	FRONT LAWN	73	45	13	67	9350	0.9	0.3	15	6	18000	3050	415	0.5	110	19	29
GEORGE	41	FRONT BED	63	260	14	230	9200	0.7	0.8	20	7	17000	3000	410	0.7	110	21	28
		BACK LAWN	38	94	15	120	10000	0.7	0.3	16	6	15000	2500	250	0.7	80	26	27
GEORGE	50	FRONT LAWN	88	57	14	92	9850	0.7	0.4	17	7	18000	3550	420	1	110	25	27
GEORGE	48	FRONT LAWN	56	63	14	83	9950	0.7	0.3	17	6	18500	3700	390	0.7	100	17	29
		BACK LAWN	47	36	15	74	11500	0.9	0.3	17	7	19500	3400	360	1	92	16	31
		GARDEN	20	16	10	47	8300	0.8	0.6	14	5	14500	2650	275	0.7	92	21	25
GEORGE	42	BACK LAWN	37	57	13	91	9800	0.7	0.4	14	6	15000	2750	335	0.8	87	24	25
GEORGE	43	BOULEVARD	78	108	12	115	8250	0.8	0.3	14	5	15000	7250	345	0.6	160	21	27
		FRONT LAWN	42	49	12	79	9350	0.6	0.2	15	6	19500	2600	360	0.8	88	14	33
		BACK LAWN	27	35	11	68	9750	0.8	0.2	14	5	16000	1900	260	0.4	71	13	30
		GARDEN	24	58	10	91	9600	0.7	0.3	13	5	15500	1900	215	0.6	67	15	28
GEORGE	44	BOULEVARD	74	110	13	120	8650	0.7	0.5	19	6	17000	7300	385	0.6	220	21	29
		FRONT LAWN	36	40	13	61	10500	1	0.3	19	6	19000	2400	345	1	90	17	34
		BACK LAWN	21	30	14	52	9400	0.9	0.4	16	5	17500	1950	310	1.1	67	13	31
PLEASANT	15	FRONT LAWN	83	89	14	104		0.7	0.8	27	8	16000	3250	430	0.8			27
		BACK LAWN	34	48	9	66		<0.5	0.5	16	6	11000	1700	240	0.6			22
PLEASANT	27	BOULEVARD	175	102	15	130	7650	0.7	0.5	20	6	14500	5300	340	1	96	27	25
		FRONT LAWN	135	86	14	120	8300	1	0.7	35	7	15000	2900	320	1.2	94	21	28
		BACK LAWN	46	49	12	72	8700	0.8	0.2	18	6	14500	2150	315	0.4	87	19	27
		BACK BED	32	49	13	86	9450	0.7	0.3	18	7	16000	2950	395	0.6	104	26	27
PLEASANT	28	FRONT LAWN	105	110	15	92	7650	0.9	0.2	15	7	16000	2650	380	0.5	76	21	28
		BACK LAWN	67	180	13	120	7850	0.7	0.3	14	7	14000	2050	330	1	72	27	25
		GARDEN	55	170	13	105	9350	0.8	0.4	15	7	14000	1800	340	0.8	95	33	26

TABLE 1: SOIL METAL CONCENTRATIONS (PPM, DRY WT) * DETECTED IN THE VICINITY OF BURNSTEIN CASTINGS, CATHERINE ST., ST. CATHARINES - MARCH 1988 THROUGH AUGUST 1989

STREET	LOCATION FIG 1	SAMPLING SITE	Cu	Pb	Ni	Zn	Al	Be	Cd	Cr	Co	Fe	Mg	Mn	Mo	Na	Sr	V
PLEASANT	29	BOULEVARD	365	119	17	125	7350	0.8	0.6	16	7	14000	5100	360	0.9	91	26	25
		FRONT LAWN	280	125	15	110	7800	0.9	0.3	15	6	14500	2750	345	0.6	97	19	27
		BACK LAWN	170	145	17	110	7150	0.6	0.3	14	6	15000	2900	440	0.4	80	25	24
RODMAN	60	BOULEVARD	210	185	18	220	8800	0.8	0.7	18	7	16000	6700	390	1.2	155	24	26
		FRONT BED	205	260	15	325	8100	0.6	0.7	21	7	16500	4000	385	0.8	130	19	26
		BACK LAWN	56	24	10	43	8300	0.6	0.1	11	5	12500	2350	375	0.8	84	23	19
RODMAN	65	BOULEVARD	200	123	14	155	7050	0.7	0.4	20	6	15500	7050	445	1.1	135	22	24
		FRONT LAWN	76	68	12	88	8600	0.6	0.3	16	6	15500	2400	345	0.7	103	13	26
RODMAN	61	BOULEVARD	200	160	14	175	7550	0.7	0.4	18	6	14500	7250	400	1	110	27	24
		BACK LAWN	185	255	14	185	9250	0.6	0.3	19	8	16500	1800	270	1.2	78	13	28
RODMAN	64	BOULEVARD	165	150	15	155	7650	0.7	0.5	20	6	16000	11500	475	1	130	33	24
		FRONT LAWN	140	125	16	130	8550	0.7	0.4	20	6	14500	3600	385	1	80	19	26
		BACK LAWN	71	74	13	112	10800	0.7	0.2	16	7	15500	2050	310	0.9	82	12	27
		GARDEN	54	92	13	150	8550	0.8	0.4	15	7	15000	2250	375	1.2	80	14	25
RODMAN	62	BOULEVARD	150	170	16	205	8500	1	0.4	18	6	16500	6700	405	1.2	135	24	28
		BACK LAWN	115	165	13	170	8350	<0.5	0.7	16	6	15000	1800	270	1	88	18	26
		GARDEN	71	150	12	175	8500	0.7	0.3	17	6	14000	1550	245	0.9	80	19	26
RODMAN	63	BOULEVARD	150	130	17	210	8400	0.7	0.6	24	6	17000	5950	380	1.1	125	19	28
		SIDE BED	135	150	16	260	9300	0.8	0.7	18	7	18500	2850	360	0.9	165	22	32
		BACK LAWN	115	95	12	130	9050	0.7	0.5	22	6	15500	1750	250	0.7	79	16	28
RUSSELL	35	BACK LAWN	31	115	12	89	9150	0.8	0.2	15	7	14500	1750	280	0.6	64	17	27
		GARDEN	72	140	12	101	10025	0.8	0.3	15	7	14250	1775	263	0.5	68	24	28
RUSSELL	36	BOULEVARD	40	110	13	110	8450	0.6	0.6	15	5	14000	5450	320	1	160	21	22
		FRONT LAWN	26	125	15	120	10500	0.9	0.5	16	6	15500	2500	350	0.8	87	14	29
		BACK LAWN	19	103	11	103	8550	0.7	0.4	14	5	13000	1950	235	0.8	74	17	23
RUSSELL	34	BOULEVARD	41	120	17	120	9100	0.6	0.6	19	7	15000	4500	345	0.6	115	20	25
		BACK LAWN	28	68	11	82	9550	0.8	0.3	15	6	14000	1700	250	0.7	65	12	26
		GARDEN	46	130	13	170	9550	0.7	0.5	18	7	15000	2150	295	0.7	72	18	26
RUSSELL	37	BOULEVARD	63	165	17	135	9100	0.8	0.6	22	6	16000	7800	370	1.1	205	25	25
		FRONT LAWN	28	103	12	104	7950	0.7	0.5	14	5	14500	2400	340	1	90	14	24
		FRONT BED	27	175	13	195	8100	0.6	0.7	15	6	16000	3000	445	0.4	98	17	25
		BACK LAWN	26	90	11	104	8450	0.7	0.3	15	5	13000	1600	210	0.6	74	16	25
RUSSELL	33	BACK LAWN	36	125	14	165	8850	0.7	0.5	16	7	14500	1950	290	0.8	70	17	25
		FRONT BED	26	94	12	150	9450	0.7	0.5	15	7	14000	1700	300	0.6	66	15	25

TABLE 1: SOIL METAL CONCENTRATIONS (PPM, DRY WT) * DETECTED IN THE VICINITY OF BURNSTEIN CASTINGS, CATHERINE ST., ST. CATHARINES - MARCH 1988 THROUGH AUGUST 1989

STREET	LOCATION FIG 1	SAMPLING SITE	Cu	Pb	Ni	Zn	Al	Be	Cd	Cr	Co	Fe	Mg	Mn	Mo	Na	Sr	V
RUSSELL	17	BOULEVARD	57	140	14	125	8550	0.7*	0.8	28	5	15500	7650	360	0.9	180	23	23
		FRONT LAWN	42	130	13	104		0.6	1	33	7	14500	2900	365	0.5			28
		BACK LAWN	34	95	11	105		0.6	0.6	19	7	14000	2050	320	0.3			27
RUSSELL	38	BOULEVARD	52	110	13	97	9100	0.9	0.6	16	6	15500	7450	375	0.8	195	26	25
RUSSELL	32	BOULEVARD	335	250	18	190	8350	0.7	0.7	18	6	15500	7200	395	1.2	130	22	24
RUSSELL	39	BOULEVARD	115	110	14	110	8300	0.7	0.4	16	6	15000	6150	400	1.1	190	21	24
		BOULEVARD	580	265	19	245	7300	0.7	0.9	20	6	14500	12000	400	1.2	170	34	22
RUSSELL	18	FRONT LAWN	1000	250	22	260		0.7	1.2	32	7	14000	5150	375	0.9			24
		BACK LAWN	373	190	18	240		0.7	1.7	23	8	14500	3100	360	0.8			25
RUSSELL	53	FRONT BED	270	325	17	450	8750	0.8	0.8	21	9	16500	2750	325	1.1	97	18	29
RUSSELL	54	FRONT LAWN	725	265	22	240	9350	0.7	0.6	23	7	16000	4500	335	1.5	115	22	26
RUSSELL	19	BOULEVARD	325	145	17	135	8900	0.7	0.5	18	6	16000	8700	395	1	175	29	25
		FRONT LAWN	640	190	19	270		0.6	0.9	22	7	14000	4200	320	0.6			25
		(15-20CM)	57	120	15	130	12000	0.9	0.5	18	8	17000	2700	300	1.3	98	20	30
		BACK LAWN	215	160	14	195		0.6	0.7	19	7	13500	2300	270	0.5			27
		GARDEN	160	320	14	280	10000		0.7	19	10	15000		290	1.3	86	23	28
		GARDEN	150	210	17	220	11000		0.8	22	10	15000		280	1.5	130	28	29
RUSSELL	55	FRONT LAWN	135	94	17	110	12000	1.2	0.2	19	8	17500	4300	385	1.5	115	29	31
		BACK LAWN	205	125	14	275	9350	0.9	0.5	17	7	16000	4750	350	1	89	21	28
RUSSELL	7	BOULEVARD	70	47	13	69	10000	0.9	0.3	18	6	16500	5850	420	0.7	225	28	27
		(0-2CM)	69	54	15	94			0.4	19	7	10500		315	<1			19
RUSSELL	56	BACK LAWN	380	190	17	255	8350	0.6	0.9	21	8	15000	2700	375	1.1	85	24	24
RUSSELL	57	FRONT LAWN	220	101	14	140	8750	0.6	0.5	16	6	13500	4150	295	0.9	105	26	22
		BACK LAWN	275	120	14	225	7800	0.7	0.5	19	6	15000	2000	250	0.7	77	16	26
RUSSELL	20	BOULEVARD	110	85	10	89	8150	0.7	0.3	14	5	13000	5750	280	0.6	200	28	22
		FRONT LAWN	695	230	20	240		0.7	0.9	23	7	14000	5000	365	0.8			24
		(15-20CM)	31	46	11	55	8600	1	0.2	15	6	15000	2600	330	1	88	19	27
		BACK LAWN	260	120	12	175		<0.5	1	20	7	13000	1800	255	0.7			26
RUSSELL	59	BOULEVARD	180	105	13	110	8100	1	0.4	17	6	16000	12000	530	0.9	195	35	26
RUSSELL	66	BOULEVARD	105	84	14	105	9000	0.9	0.3	17	7	15500	7350	450	1.2	175	28	25

TABLE 1: SOIL METAL CONCENTRATIONS (PPM, DRY WT) * DETECTED IN THE VICINITY OF BURNSTEIN CASTINGS, CATHERINE ST., ST. CATHARINES - MARCH 1988 THROUGH AUGUST 1989

STREET	LOCATION FIG 1	SAMPLING SITE	Cu	Pb	Ni	Zn	Al	Be	Cd	Cr	Co	Fe	Mg	Mn	Mo	Na	Sr	V
RUSSELL	21	FRONT LAWN	58	69	9	130		0.8	0.6	17	7	11500	2300	360	1			23
		BACK LAWN	48	53	9	92		0.6	0.4	15	6	11500	1800	260	0.5			22
RUSSELL	23	FRONT LAWN	36	225	13	120		0.6	0.8	21	7	15000	7950	480	0.3			27
STUART	45	BOULEVARD	67	85	14	85	9450	0.9	0.2	19	6	17000	6000	355	0.9	130	25	29
STUART	46	FRONT LAWN	75	35	15	65	11000	1	0.2	22	8	21000	3900	420	1	105	21	34
		BACK LAWN	47	34	11	57	9500	0.7	0.2	16	6	16500	2300	315	0.9	78	13	27
STUART	47	FRONT LAWN	61	41	13	65	8900	1.5	0.1	18	6	16000	3950	430	0.6	86	23	25
		BACK LAWN	88	56	13	97	9050	0.8	0.1	15	6	17000	2600	495	0.7	80	32	26
		BACK BED	60	36	15	81	10500	1	0.2	16	7	18500	3400	435	0.7	92	23	28
WOLSELEY	70	FRONT LAWN	28	63	15	92	10000		0.3		8							
		BACK LAWN	21	96	11	78	8550		0.3		6							
WOODLAND	69	BACK LAWN	109	220	16	230	8300	0.6	1.6	38	7	16500	2400	425	0.7	84	23	30
		GARDEN	49	205	13	230	8050	0.8	0.8	19	7	15000	2850	340	0.9	79	31	28
WOODLAND	68	BACK LAWN	43	51	14	78	8900	0.7	0.2	23	6	17500	1750	325	0.7	81	14	33
		BACK BED	36	62	12	105	9350	0.8	0.1	21	6	18500	1750	395	0.6	76	14	36
WOODLAND	67	BOULEVARD	73	110	20	160	7300	1	0.4	24	6	14000	5050	420	0.4	110	22	27

TABLE 1: SOIL METAL CONCENTRATIONS (PPM, DRY WT) * DETECTED IN THE VICINITY OF BURNSTEIN CASTINGS, CATHERINE ST., ST. CATHARINES - MARCH 1988 THROUGH AUGUST 1989

STREET	LOCATION FIG 1	SAMPLING SITE	Cu	Pb	Ni	Zn	Al	Be	Cd	Cr	Co	Fe	Mg	Mn	Mo	Na	Sr	V
PUBLIC PROPERTIES																		
CATHERINE	2a	FRONT LAWN (0-2CM)	78	175	15	215			1.1	22	8	13000		460	<1			26
(HIGH SCHOOL)	2b	TRACK LAWN (0-2CM)	28	59	13	94			0.2	14	8	11500		305	<1			28
	2c	TRACK LAWN (0-2CM)	12	18	13	41			0.2	16	8	14000		325	<1			26
	2d	TRACK LAWN (0-2CM)	17	52	12	62			0.3	13	8	11000		305	<1			22
CATHERINE	3a	BOULEVARD	98	105	17	130		0.8	0.8	20	7	14500	5150	375	0.4			26
(PUBLIC PARK)		(0-2 CM)	125	89	18	125			0.5	19	8	13000		350	<1			23
		(15-20CM)	27	49	10	57		0.7	0.6	16	7	16000	2700	500	0.3			27
	3b	LAWN (0-2CM)	48	30	9	58			0.3	13	7	12000		330	<1			23
CATHERINE	77	BOULEVARD	1150	300	28	270	5850	2.5	0.9	28	6	14500	15500	465	1.4	160	31	24
CATHERINE	78	BOULEVARD	330	150	26	225	9200	2.4	0.8	26	8	17000	7000	470	1.4	165	25	36
CATHERINE	79	BOULEVARD	100	135	15	275	7250	1.3	1.1	22	7	16000	5800	410	0.6	96	19	27
GEORGE	72	BOULEVARD	195	140	15	150	6900	0.6	0.5	20	6	16000	7400	395	0.8	120	22	26
		(10-15 CM)	58	120	13	97	7500		0.3		6							
GEORGE	75	BOULEVARD	10000	575	75	825	5100	1.7	0.6	40	6	13500	13500	430	2.8	145	29	22
		(15-20 CM)	120	66	13	77	7500		0.3		6							
		(15-25 CM)	89	62	13	72	7800		0.3		6							
		(30-35 CM)	25	28	8	33	7800		0.2		6							
		(50-55 CM)	17	24	9	33	8900		0.2		6							
GEORGE	76	BOULEVARD	2400	270	53	540	5750	1.9	0.5	32	6	14000	12000	380	1.6	92	24	21
		(10-15 CM)	180	95	15	110	7000	<0.5	0.4	15	6	13000	4600	330	0.5	100	16	21
GEORGE	73	BOULEVARD	1450	165	26	250	6450	1.9	0.3	24	6	15000	9850	500	0.6	110	27	23
		(10-15 CM)	280	90	15	120	7600	0.6	0.4	15	7	15000	4200	400	0.4	160	19	24
GEORGE	74	BOULEVARD	1400	130	26	280	6100	1.8	0.3	17	5	12000	4400	310	0.3	79	15	21
GEORGE	71	BOULEVARD	54	66	24	110	7000	1.1	0.3	28	8	30500	4850	580	1.8	82	19	25
HENRY	1c	FRONT LAWN	28	30	10	54		0.6	0.5	17	7	14500	3100	315	0.4			27
(JR SCHOOL)	1b	PLAYFIELD	135	40	10	130		0.6	0.5	14	6	11500	3350	290	0.4			20
		(0-2CM)	140	37	9	89			0.3	13	6	9650		350	<1			18
	1a	PLAYFIELD	230	59	10	87		0.6	0.4	13	6	11000	2000	220	0.4			20
		(0-2CM)	460	74	15	150			0.3	16	6	10500		230	<1			20
		(15-20CM)	42	49	10	61		<0.5	0.5	12	6	11000	1800	240	<0.2			20
	1e	PLAYFLD (0-2CM)	50	41	10	125			0.2	12	7	10500		265	<1			20
	1d	PLAYFLD (0-2CM)	63	46	11	69			0.3	14	7	12000		310	<1			22

TABLE 1: SOIL METAL CONCENTRATIONS (PPM, DRY WT) * DETECTED IN THE VICINITY OF BURNSTEIN CASTINGS, CATHERINE ST., ST. CATHARINES - MARCH 1988 THROUGH AUGUST 1989

STREET	LOCATION FIG 1	SAMPLING SITE	Cu	Pb	Ni	Zn	Al	Be	Cd	Cr	Co	Fe	Mg	Mn	Mo	Na	Sr	V
RUSSELL	5c	BOULEVARD	170	55	17	90	11000	0.9	0.2	19	7	16000	4800	360	0.8	107	20	27
(COMM CENTER)	5b	W LAWN	275	63	16	78	12000	0.7	0.2	17	6	14500	2650	265	0.7	66	14	26
	5a	S LAWN	185	66	14	69		0.8	0.5	18	8	14500	3650	290	0.4			25
		(0-2CM)	985	74	29	120			0.6	27	9	15500		305	1.2			26
		(10-15CM)	520	210	18	180		0.8	1	24	9	20000	4800	440	0.5			28
RUSSELL	6	BOULEVARD	104	58	12	84		0.6	0.6	16	6	12500	5800	420	<0.2			20
(T FOX TRAIL)		(0-2CM)	295	90	22	170			0.7	22	7	13500		500	<1			20
		(15-20CM)	32	31	10	60		0.8	0.5	16	8	15000	3000	380	0.4			24
RUSSELL	4	W BLVD	225	88	17	85		0.8	0.6	21	7	15000	5350	395	0.3			24
(SR RESIDENCE)		(0-2CM)	705	94	43	145			0.5	28	7	11500		385	<1			20
		(15-20CM)	33	18	13	34		0.8	0.5	18	9	18000	2500	720	<0.2			28
		W LAWN	54	17	8	30		<0.5	0.3	12	5	11000	3500	430	<0.2			18
		(0-2CM)	220	34	13	59			0.4	14	6	10500		350	<1			20
PHYTOTOXICOLGY SECTION ULN GUIDELINES			100	500	60	500	-	-	4	50	25	35000	-	700	3	-	-	70

* AVERAGE CONCENTRATION BASED ON DUPLICATE SAMPLE RESULTS. DEPTH RESULTS REFLECT CONCENTRATION IN A SINGLE SAMPLE

** WHERE SAMPLING DEPTH IS NOT INDICATED, SAMPLING DEPTH FOR LAWN SITES IS 0-5 CM AND FOR GARDEN/BEDDING AREAS 0-15 CM

NOTE: RESULTS UNDERLINED ARE AT OR EXCEED THE PHYTOTOXICOLOGY SECTION UPPER LIMIT OF NORMAL (ULN) URBAN GUIDELINE FOR SURFACE SOIL (0-5 CM)

TABLE 2:
Metal Concentrations Detected in Maple Foliage in the Vicinity of Burnstein Castings, St. Catharines - August 1988 and 1989

Site No (see Fig 3)	Cadmium 1988	Cadmium 1989	Chromium 1988	Chromium 1989	Cobalt 1988	Cobalt 1989	Copper 1988	Copper 1989	Iron 1988	Iron 1989	Lead 1988	Lead 1989	Manganese 1988	Manganese 1989
	*Average Concentration in Foliage - parts per million, dry weight													
	Sites Closest to Burnstein Castings													
1	<0.1	<0.1	3	1	0.3	0.3	13	9	275	170	4	3	118	27
2	<0.1	<0.1	2	1	<0.2	<0.2	10	8	195	155	2	2	44	58
3	<0.1	0.1	7	4	<0.2	0.4	52	28	620	345	15	8	36	28
4	0.1	0.2	3	2	0.3	0.4	25	26	315	265	5	6	35	43
5	<0.1	0.1	2	1	<0.2	0.3	20	16	455	325	7	5	58	36
6	<0.1	0.1	2	1	<0.2	0.3	14	11	365	255	4	5	45	54
7	<0.1	<0.1	3	1	<0.2	0.3	17	12	415	170	7	3	50	37
	Sites More Remote													
8	<0.1	<0.1	1	1	<0.2	<0.2	6	6	160	140	3	2	18	19
9	<0.1	0.2	2	1	<0.2	0.3	11	9	185	180	3	3	65	48
10	<0.1	<0.1	1	<0.5	<0.2	<0.2	4	4	180	110	2	2	36	21
11	<0.1	0.1	2	1	<0.2	0.3	10	13	155	125	2	2	36	28
12	0.2	<0.1	2	1	0.3	0.3	7	7	180	120	2	2	32	30
**ULM Guidelines	2		8		2		20		1000		60		100	

* Average of duplicate sample results

** Phytotoxicology Section Upper Limit of Normal urban guidelines (results underlined exceed foliage guideline).

TABLE 2 (CONT'D):
Metal Concentrations Detected in Maple Foliage in the Vicinity of Burnstein Castings, St. Catharines - August 1988 and 1989

*Average Concentration in Foliage - parts per million, dry weight

Site No (see Fig 3)	Molybdenum 1988	Molybdenum 1989	Nickel 1988	Nickel 1989	Vanadium 1988	Vanadium 1989	Zinc 1988	Zinc 1989	Beryllium 1988	Aluminum 1989	Sodium 1989	Strontium 1989
						Sites Closest to Burnstein Castings						
1	0.6	0.4	2	1	<0.5	<0.5	31	29	<0.1	63	8	22
2	0.5	0.3	1	1	<0.5	<0.5	36	21	<0.1	50	11	13
3	2.1	1.0	12	4	<0.5	0.6	79	69	<0.1	92	23	29
4	2.8	1.2	4	2	<0.5	0.6	72	72	<0.1	95	25	24
5	0.6	0.5	2	1	<0.5	<0.5	40	40	<0.1	120	14	23
6	0.5	0.6	1	1	<0.5	<0.5	20	22	<0.1	115	170	24
7	0.8	0.4	3	1	<0.5	<0.5	49	37	<0.1	76	23	19
						Sites More Remote						
8	0.3	0.4	<0.5	<0.5	<0.5	<0.5	18	23	<0.1	77	17	42
9	0.7	0.6	1	1	<0.5	<0.5	34	25	<0.1	64	15	23
10	0.2	<0.2	<0.5	<0.5	<0.5	<0.5	29	23	<0.1	52	11	22
11	0.3	0.4	1	<0.5	<0.5	<0.5	32	35	<0.1	43	10	30
12	0.3	0.4	1	<0.5	<0.5	<0.5	39	41	<0.1	45	15	35
**ULN Guidelines	1.5		7		5		250		-	500	350	-

* Average of duplicate sample results

** Phytotoxicology Section Upper Limit of Normal urban guidelines (results underlined exceed foliage guideline).

TABLE 3:

Metal Levels (ppm, dry wt.) Detected in Vegetable Produce From Gardens Close to Burnstein Castings, St. Catharines, Compared to Levels Found in Remote Rural Gardens - August 1989

Element	Beet		Carrot	
	Foliage	Roots	Foliage	Roots
Aluminum	**140-180**	**21-24**	**150**	**19**
	100	45	120	58
Cadmium	**0.2-0.3**	**<0.1-0.2**	**0.1**	**<0.1**
	0.3	0.2	0.3	0.2
Chromium	**1.4-2.0**	**<0.5-0.8**	**0.9**	**<0.5**
	2	0.6	0.8	0.6
Cobalt	**0.5-0.6**	**<0.2**	**0.6**	**<0.2**
	0.7	0.3	0.3	<0.2
Copper	**8-9**	**7-9**	**6**	**4**
	8	8	6	4
Iron	**200-220**	**48-59**	**180**	**47**
	120	76	140	80
Lead	**1.2-1.6**	**<0.5**	**2.5**	**<0.5**
	<0.5	<0.5	<0.5	<0.5
Manganese	**43-110**	**17-35**	**43**	**10**
	110	35	52	16
Molybdenum	**0.8**	**<0.2-0.2**	**1.5**	**<0.2**
	0.6	<0.2	0.4	<0.2
Nickel	**<0.5-0.6**	**<0.5**	**<0.5**	**<0.5**
	0.8	<0.5	<0.5	<0.5
Sodium	**11000-12000**	**1100-4500**	**670**	**660**
	8700	2500	740	1200
Strontium	**27-33**	**11-12**	**47**	**10**
	28	11	33	10
Vanadium	**<0.5-2.5**	**<0.5**	**<0.5**	**<0.5**
	2.5	<0.5	<0.5	<0.5
Zinc	**24-32**	**32-39**	**21**	**16**
	19	41	35	29

Note: Non-bold values (on 2nd line) reflect levels found in remote control gardens. Where no range is shown, levels between sites were similar or only a single site was sampled

TABLE 3 (Cont'd):
Metal Levels (ppm, dry wt.) Detected in Vegetable Produce From Gardens Close to Burnstein Castings, St. Catharines, Compared to Levels Found in Remote Rural Gardens - August 1989

Element	Chard Foliage	Cucumber Fruit	Tomato Fruit	Kale * Produce
Aluminum	**15** 65	**<5** -	**<5** <5	**27** 28
Cadmium	**0.3** 0.3	**<0.1** -	**<0.1** <0.1	**<0.1** 0.4
Chromium	**1.4** 1.0	**0.6** -	**<0.5** <0.5	**0.7** 0.9
Cobalt	**0.6** 0.6	**<0.2** -	**<0.2** <0.2	**0.3** 0.7
Copper	**10** 12	**8** -	**2-4** 3	**3** 4
Iron	**63** 140	**47** -	**13-27** 16	**66** 110
Lead	**<0.5** <0.5	**<0.5** -	**<0.5** <0.5	**2** 3
Manganese	**47** 150	**14** -	**5** 7	**22** 52
Molybdenum	**1.2** 0.7	**1.3** -	**<0.2** <0.2	**1.3** 1.1
Nickel	**0.6** 0.7	**<0.5** -	**<0.5** <0.5	**<0.5** 2
Sodium	**13000** 30000	**120** -	**200-290** 170	**835** 11000
Strontium	**37** 36	**11** -	**0.9-1.7** 0.7	**39** 240
Vanadium	**<0.5** <0.5	**<0.5** -	**<0.5** <0.5	**<0.5** <0.5
Zinc	**68** 51	**31** -	**6-8** 9	**15** 18

* Kale sampled in December 1989

Note: Non-bold values (on 2nd line) reflect levels found in remote control gardens. Where no range is shown, levels between sites were similar or only a single site was sampled

TABLE 4:
Amount and Frequency of Rain and Prevailing Wind Direction Recorded at the Niagara District Airport, St Catharines - June, July and August, 1988 & 1989

Month /Year	June		July		August		June - August*	
	Rainfall in millimeters - Amount & Frequency							
	Amt.	Freq.	Amt.	Freq.	Amt.	Freq	Amt.	Freq.
1988	19	7	106	14	66	11	157	27(4)
1989	103	18	35	8	8	9	145	34(3)
Norm	68	8	69	6	81	9		
	Prevailing Wind Direction							
1988	SW		SSW		SW			
1989	SW		S		SW			
Norm	SW		SW		SW			

* Rainfall during June through to day preceding foliage collection in 1988 (Aug. 23) and 1989 (Aug. 28)

( ) Number of days with rain during two week period prior to date of foliage collection

Figure 1: Soil Collection Sites in the Vicinity of Burnstein Castings - March 1988 through August 1989

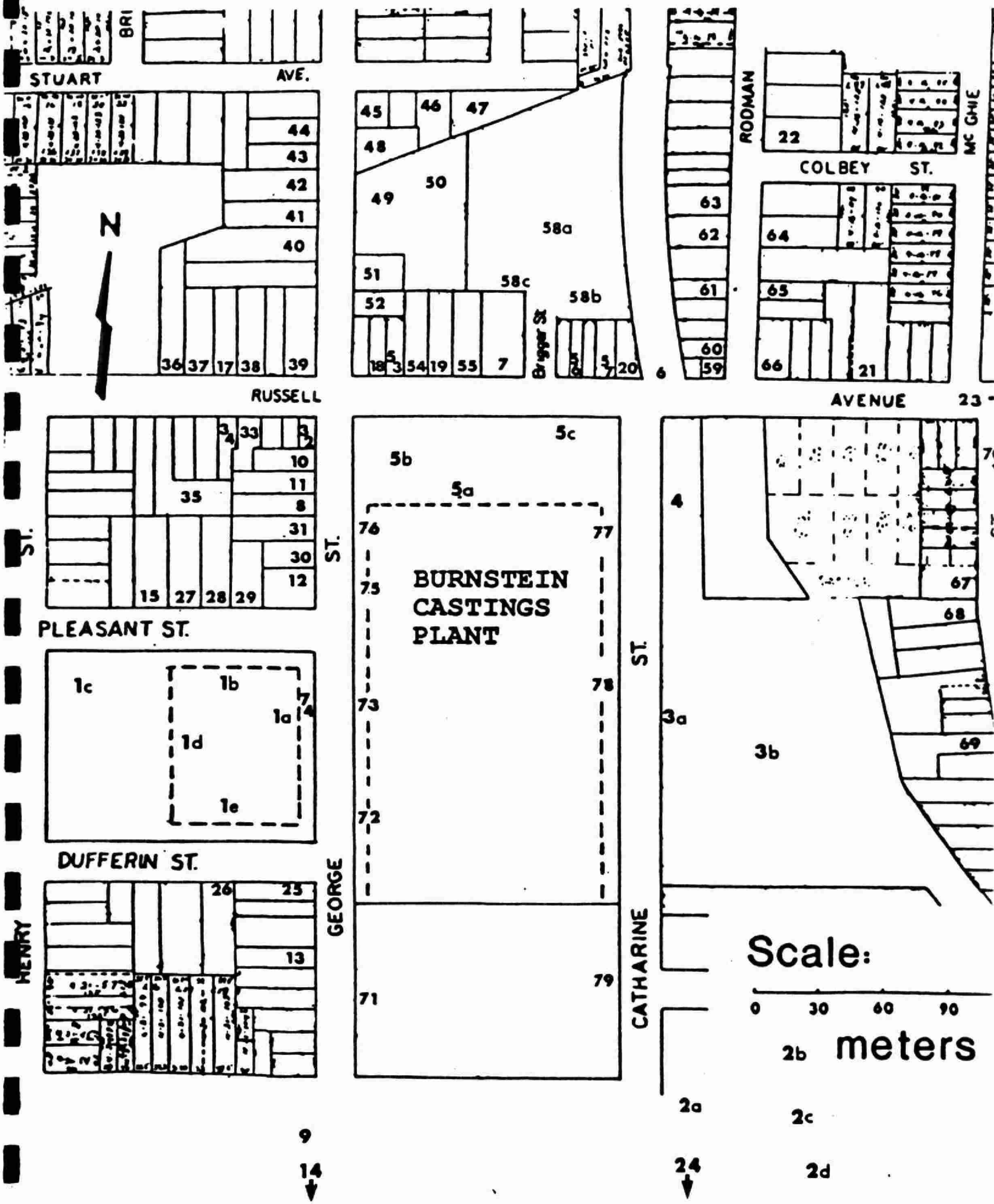


Figure 2: Contour of 100 ppm Copper in Surface Soil in the Vicinity of Burnstein Castings

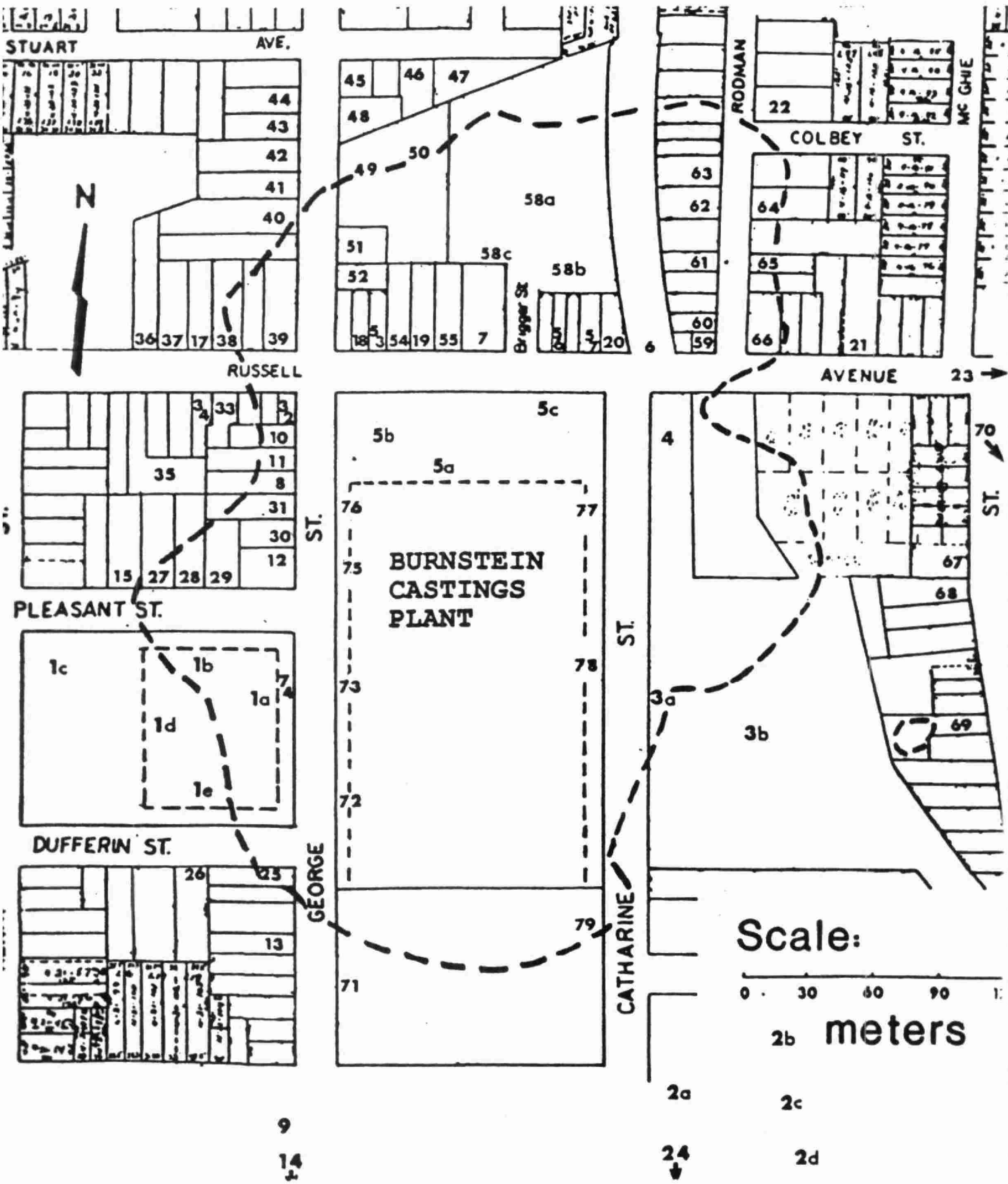
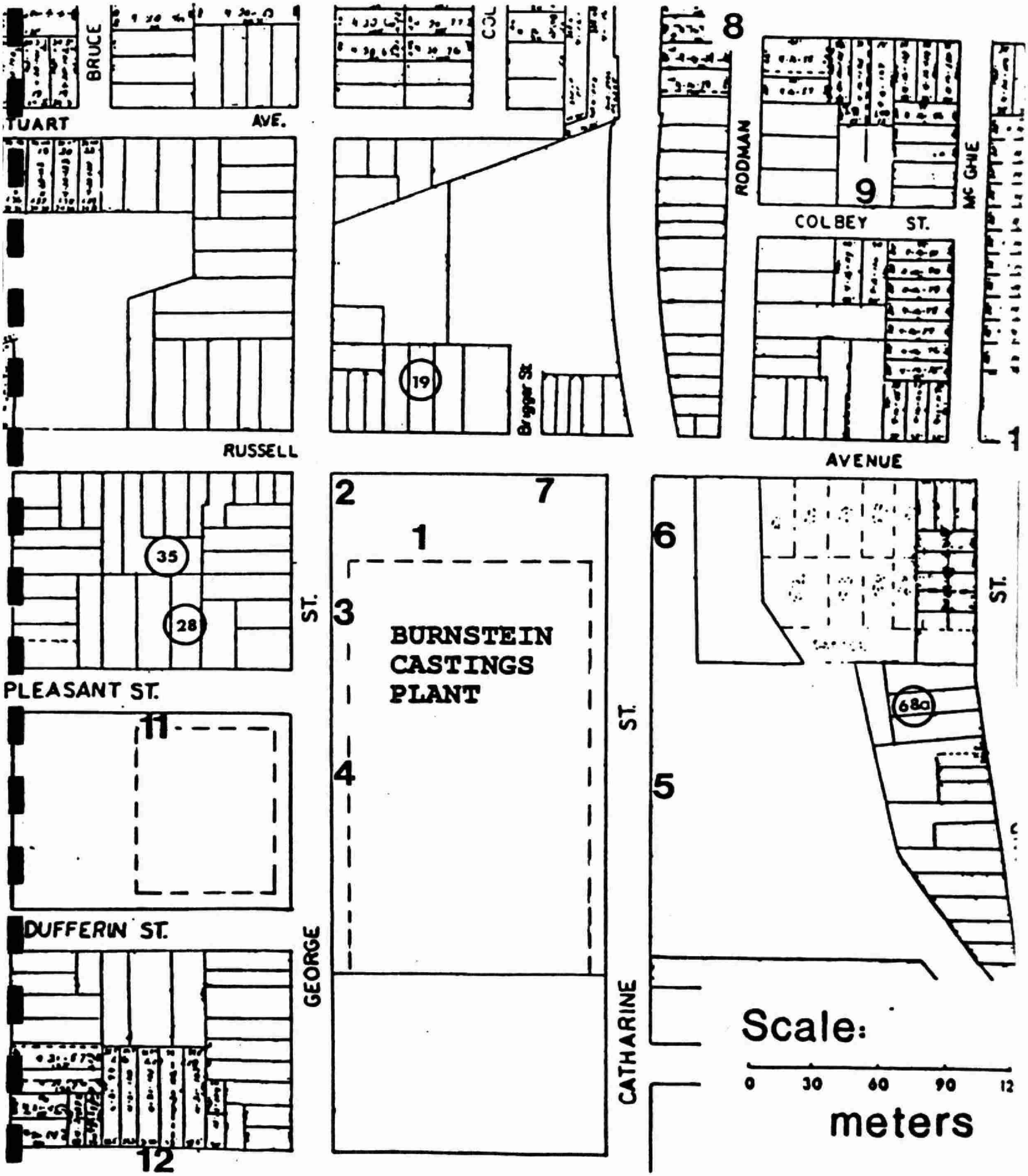


Figure 3: Foliage Sites (Bold Numbers) Sampled in August 1988 and 1989. Garden Vegetable Sites (O) Sampled in the Immediate Vicinity of Burnstein Castings during 1989 also are Shown



APPENDIX

PHYTOTOXICOLOGY BIOASSAY STUDIES ON SOILS COLLECTED IN THE VICINITY OF BURNSTEIN CASTINGS, ST. CATHARINES

INTRODUCTION

Copper contamination of soils commonly occurs in the vicinity of mines, smelters, casting plants, and metal refiners. The largest area of contamination in Ontario is around Sudbury, where average soil concentrations are greater than 450 ug/g in a 30 km radius around the smelters. Most Ontario soils have much lower concentrations. The average copper concentrations in agricultural soils in southern Ontario is reported to be 25.4 ug/g by Frank et al. (1976) and 18.9 ug/g by Whitby et al. (1978). General surveys of undisturbed surface soils in Ontario report slightly higher copper concentrations of 57.4 ug/g (Wall and Marsh 1988) and 42.2 ug/g (Marsh et al. (1989). Localized contamination can, nevertheless, result in public concern. The Burnstein castings plant in St. Catharines emits copper which has resulted in elevated copper concentrations in a residential area in the vicinity of the plant. Soil samples collected from a boulevard immediately adjacent to the plant had copper concentrations in the surface (0-5 cm) soil of greater than 11,000 ug/g.

The relationship between copper concentrations in plants and soil copper concentration is extremely poor, since many factor influence copper uptake. The most important factors are soil pH, organic matter content, cation exchange capacity and iron and manganese oxides (Adriano 1986). Copper is almost completely unavailable to plant roots at soil pH levels greater than 7. Organic matter can effectively bind up the copper, as can oxides of iron and manganese. In order to determine the exchangeable or available copper in a soil, several extractants, such as water, dilute HCl or DPTA, have been used. These methods may only be of value if appropriate calibration curves of extractable soil metal compared to plant uptake are available for the particular crops and soils under consideration (Davis 1979). The best method to determine the toxicity of a soil is through the use of a bioassay in which plants are grown in the soil and their growth and metal uptake are measured directly.

Bioassays are often performed using a control soil or media to which metal salts are added to create a range of concentrations. The problem with this approach is that the results will depend on the form of the copper added and the length of time allowed for the copper to equilibrate with the soil media. If insufficient time is allowed or if the copper is added in a highly available form the concentration at which toxicity is observed may be much lower than would be the case under naturally contaminated soil conditions.

This paper reports on two bioassay experiments which were performed from June 1989 to January 1990 to determine the effect of soil collected in the vicinity of Burnstein Castings in St. Catharines on the growth of common garden vegetables.

METHODS

Bioassay #1

Surface soil (0-5 cm) was collected in June, 1989 from 5 properties (Sites 30, 67, 75, 77, and 78) in the immediate vicinity of Burnstein Castings (Figure 1). These soils represented a range of "total" copper concentrations from 73 to 11,405 ug/g copper. Two additional treatments (895 and 6,438 ug/g copper) were produced by mixing soils.Table 1 gives the soil chemical data from these sites. The soils were analyzed by Agri-Food Laboratories, Guelph, Ontario. The pH was taken using the water thin paste method. Organic matter analysis was by dichromate digestion followed by a colourimetric determination. Phosphorus analysis was by sodium bicarbonate extraction and colourimetric determination. Potassium analysis was by ammonium acetate extraction and atomic emission determination. Magnesium and calcium were analyzed using ammonium acetate and atomic absorption determination. Zinc, iron and copper were determined by EDTA extraction and atomic absorption determination. Manganese was determined by phosphoric acid digest and atomic absorption determination and boron by hot water extraction and ICP determination.

Twenty 130 mm diameter pots were filled with each treatment soil. Ten pots were seeded with "Cherry belle" radish seeds and ten pots with "Tendergreen stringless" beans on 7 July 1989. The radish plants were harvested on 18 August 1989 and the bushbeans on 30 August 1989. Pots were randomized in the Phytotoxicology greenhouse and watered daily with deionized water. Natural light was supplemented with fluorescent and incandescent lights to give a 12 hour photoperiod.

Radish plants were harvested 42 days after seeding. Shoots were separated from the roots. Leaf area was determined using a Licor model 3100 leaf area meter. The hypocotyls were washed in tap water and the diameter was measured using Max-Cal electronic digital callipers. The shoots were dried for 24 hours at 60°C and the hypocotyls for 48 hours before being weighed. Chemical analysis of the foliage and hypocotyls was carried out at the M.O.E. Laboratory Services Branch laboratory at Resources Road. There was insufficient plant material in soil treatments greater than 1852 ug/g copper to submit for chemical analysis.

Bean plants were harvested 54 days after seeding. The height of the plant was measured, the leaves were cut off at the base of the blade and leaf area was measured. The number of leaves and pods were counted. The entire shoot was dried in a drying oven for 24 hours at 60°C. The roots were carefully washed from the soil, dried for 24 hours at 60° C and weighed.

Analysis of variance and statistical contrasts could not be carried out due to poor germination in several treatments, including the controls.

Bioassay #2

Soil for this bioassay was collected from site 75 (Figure 1). Two soils were collected from this site. The first, the surface 0-5 cm of the soil, was collected as highly copper contaminated soil and the second, soil from 15 - 100 cm, was collected as uncontaminated soil. These soils had very similar textures but differed in organic matter

content, soil nutrient status and pH. Finely ground peat moss was added to the uncontaminated subsoil to match the organic matter content of the surface soil. This addition also corrected differences in the pH of the soils. These two soils were mixed in various ratios to create the following soil copper concentrations: 63, 403, 753, 1333, 2233, 3600 and 8066 ug/g. Table 3 shows the chemical composition of the seven treatment soils. These soils were analyzed by the Agri-Food Laboratories in Guelph using the same methods as in Bioassay #1.

Each soil treatment was potted in ten 130 mm diameter plastic pots. Half of the pots were fertilized with N, P, and K to meet the Ontario Ministry of Agriculture and Food recommendations for moderate fertility mineral soil. The quantity of fertilizer added for the three crops is given in Table 4.

Three crops were grown in this bioassay, "Cherry belle" radish, "Tendergreen stringless" bean and "Long-standing Bloomsdale" spinach. The radish seeds were planted on 20 October 1989 and harvested on 28 November 1989. The beans were planted on 5 December 1989 and harvested on 15 January 1990 and the spinach was planted on 17 December 1989 and harvested on 26 January 1990.

The radish and beans were harvested using the same methods as in Bioassay #1. The spinach was small when harvested. The leaves were counted, opened out and the entire shoot put through the leaf area meter. The shoots were then oven dried for 24 hours at 60 C and weighed. The spinach roots were too small and fine to harvest.

The experiment was analyzed as a randomized complete block design with five blocks using the statistical program Statgraphics, STSC. The protected LSD multiple comparison test was used to determine significant differences among treatments where appropriate.

RESULTS

Bioassay #1

The properties of the seven soils used in this bioassay are given in Table 1. Organic matter, pH and cation exchange capacity are three of the most important determinants of copper availability. These soils all had a pH of approximately 7.0. Organic matter is also very similar for all soils, approximately 7%, with the exception of the control (73 ug/g copper) soil which only had 2.8%. The cation exchange capacity varied among treatments and tended to decrease with increasing copper concentration.

Figure 2 to 5 shows the pattern of growth of "Cherry belle" radish plants with respect to soil copper concentration. The parameters measured, leaf area, dry weight, hypocotyl diameter and hypocotyl dry weight all show the same pattern of decreasing growth with increasing soil copper concentration. The one anomalous value is for the plants grown in 1852 ug/g copper which had better growth than any treatment, except the control. This soil had the highest potassium concentrations of all soils, an element which was frequently low or deficient in these soils (Table 1). A graph of leaf area compared to potassium concentration, Figure 6, shows a very strong relationship between leaf area and soil potassium concentration for all treatments, except the control.

Figures 7 to 11 show the growth pattern of "Tendergreen stringless" beans plants. Shoot growth generally was greatest in the control (73 ug/g) soil and declined with

increasing soil copper concentration. This pattern was clearest in Figure 8 of leaf area. Shoot dry weight, Figure 9, shows this general pattern. However, the 1852 ug/g treatment, as with the radish, had better growth than any of the other treatments except the control.

Root growth follows quite a different pattern (Figure 10). Greatest growth occurred in the intermediate soil copper concentratations, peaking in the 1852 ug/g soil. The roots of the 6438 and 11405 ug/g soils, although of a similar weight to the control, were thickened and stunted and occupied a very small zone of the soil immediately around the base of the stem. Pod production was low averaging about 1.5 pods per plant. The average number of pods was greatest in the control and decreased with increasing copper concentration (Figure 11).

The symptoms of copper toxicity are described as a general chlorosis and stunting (Lepp 1981) and poorly developed and discoloured root systems (Adriano 1986). Bean plants growing in the soils with the highest copper concentrations (6438 and 11,405 ug/g soil copper) were small with chlorotic and bleached leaves. The roots of these plants were also poorly developed. The leaves of the radish plants in all treatments had an anthocyanin pigmentation along the veins, indicative of phosphorus deficiency.

Figure 12 gives the copper concentration in the radish foliage and hypocotyls. The foliage had higher copper concentrations than the hypocotyls. Foliar concentrations show a linear increase from 73 to 895 ug/g; from 895 to 1852 ug/g soil copper concentrations level off showing no increase of tissue concentration with increasing soil concentration.

Bioassay #2

Five different parameters were measured in the "Cherry belle" radish for both fertilized and unfertilized soil (Figure 13 to 24). The number of leaves was not affected by the soil copper concentration (Figure 13 and 19). Fertilization increased the average number of leaves only slightly. In the other parameters measured, leaf area, shoot dry weight, hypocotyl diameter and hypocotyl dry weight, there was a response to both soil copper concentrations and fertilization.

The unfertilized radish plants showed poor growth in the pots with 63, 403 and 3600 ug/g copper. Growth in the intermediate copper concentrations 753, 1333 and 2233 ug/g copper tended to be much better. The soil with the highest copper concentration (8066 ug/g) showed the greatest growth in the unfertilized pots.

The fertilized radish plants, in the 62 to 1333 ug/g range, had over twice the growth of the unfertilized plants. A growth reduction is evident in treatment soils with a copper concentration greater than 1333 ug/g. The highest copper treatment (8066 ug/g) had very poor growth with anthocyanin pigmentation, indicative of nutrient stress.

Tendergreen Stringless bean plants showed little response to either soil copper level or to fertilization (Figure 25 to 34). There was a tendency for the shoot dry weight to be greatest in the 2233 and 3600 ug/g copper soils. Figure 19 and 34 of root dry weight shows the lowest weight in the 8066 ug/g treatment. The roots in this treatment were thickened and stunted, concentrating in a ball around the base of the stem rather than penetrating throughout the pot.

Spinach plants grew almost twice as well in the fertilized pots as in unfertilized pots but the overall response to soil copper concentrations was similar (Figure 35 to 42). Greatest

growth was recorded in plants growing in soil from 62 to 1333 ug/g copper. At soil copper concentrations greater than 1333 ug/g there was a drastic growth reduction in the fertilized plants, particularly in leaf area and shoot dry weight (Figures 41 and 42).

Figure 43 shows the foliar and hypocotyl copper concentration compared to total soil concentrations. The foliage tends to have higher tissue copper concentrations than the hypocotyls and both show an increasing tissue concentration with increasing soil concentration. Figure 44 shows a perfect correlation between radish foliar tissue concentration and total soil copper concentration. The correlation between DPTA extractable copper concentration and tissue concentration (Figure 45) was also strong but not as good as for the total soil copper concentration.

DISCUSSION

The copper concentration in soils used for these two bioassays was extremely high. The Ontario Ministry of the Environments guidelines for the Upper Limit of Normal for urban soils is 100 ug/g, yet all soils in these bioassays were well above this, with the exception of the controls. Copper toxicity to plants has been documented for soils with much lower copper concentrations. Reuther and Smith (1953) observed a general chlorosis of citrus seedlings, in soils less than pH 5.0, when the total copper content of the soil exceeded 150 ug/g. Rhoads et al. (1988) found a 50% decrease in relative yield of tomato plants grown in 700 ug/g copper contaminated soil but no reduction in 350 ug/g soil when the pH of the soil was above pH 6.5. Hutchinson and Whitby (1973) report concentrations in soils around the Sudbury smelter of greater than 2000 ug/g. Water extracts of these high copper soils, which ranged in pH from 3.08 to 4.79, completely inhibited root elongation of several vegetable species including "Cherry belle" radish (Whitby and Hutchinson 1974). Walsh et al. (1972) estimated that a significant ($P < 0.1$) yield depression of snapbeans occurred with DTPA-extractable soil concentratations of 20 ug/g. Severe yield reductions were evident at concentrations over 40 ug/g in pH 6.7 soil. These DPTA extractable copper values are much lower than for any of the soils in Bioassay #1 or #2, with the exception of the controls. In spite of the high copper concentrations, foliar injury due to copper toxicity was only evident in the 6483 and 11,405 ug/g treatments in Bioassay #1 and in soil copper concentrations greater than 1333 ug/g in Bioassay #2.

The main factor ameliorating the effects of toxicity in these soils is probably the neutral pH. Adriano (1986) shows that for a range of soils, from organics to clays, the percent of copper adsorbed increases with pH and at approximately pH 7.0 all the copper is adsorbed. Albasel and Cottenie (1985) found that raising the pH of the soil by liming was a more efficient method of reducing plant absorption of toxic micronutrients and heavy metals than peat or chelates such as DPTA. Organic matter can, nevertheless, be highly effective in binding copper and rendering it unavailable. Crops grown on organic soils often suffer from copper deficiencies rather than excesses, even when relatively high concentrations of copper are in the soil. Mathur et al. (1984) recommend maintaining copper concentrations at 400 ug/g dry soil in muck soils (with a bulk density of 0.4 g ml-1) in order to slow down decomposition and ensure an adequate copper supply. Levesque and Mathur (1983) report that yields of oats and lettuce grown in organic soils containing 1060 ug/g copper were similar to or greater than those grown on an organic soil with 135.7 ug/g copper. The soils in the two bioassays were not organic soil but mineral soils, with organic matter contents close to 7%. Average organic matter content of temperate mineral surface soils from humid regions is 4.0 % (Brady 1974) and so these soils will tend to bind more

copper than the average soil at the same pH.

Plant tissue analysis is often used as an indicator of nutrient deficiencies or excesses. Copper is an essential micronutrient and tissue concentrations less than 4 ug/g are considered deficient (Adriano 1986). The tissue concentrations given in Figures 12 and 43 are all well above this threshold, therefore, poor growth in the unfertilized radish control plants is not due to copper deficiency. Copper concentrations greater than 20 ug/g in plant tissue are often considered toxic (Davis and Beckett 1978, Adriano 1986) although there is some controversy over the exact tissue concentration indicative of toxicity. Levesque and Mathur (1983) suggest that the threshold of copper phytotoxicity in leaves may, in some situations, be closer to 45 ug/g. In their experiments, oat and lettuce roots retained up to 700 ug/g copper without adverse effects. Rhoads et al. (1989) found that growth was not always reduced in tomato plants with tissue copper concentrations greater than 30 ug/g. The tissue concentrations in Figures 12 and 43 show the foliage in all bioassay treatments greater than the control have potentially phytotoxic copper concentrations in the tissue. However, there is a poor relationship between the foliar copper concentration and shoot dry weight (Figures 46 and 47) indicating that the concentration of phytotoxicity for radish plants may be above 80 ug/g. It is recognized that this interpretation is biased, since the data are only from samples which had sufficient growth for chemical analysis.

Figure 12 and 43 shows that the radish foliage had higher copper concentrations than the hypocotyls. The one anomalous value, 753 ug/g soil treatment in Bioassay #2, is probably due to soil contamination. Higher foliar copper concentrations indicate that copper is readily translocated and that relatively little copper is accumulated in the edible portion, the hypocotyl.

Figure 12 shows a pattern of increasing foliar and root tissue copper concentrations with increasing soil copper concentrations up to 895 ug/g. Past this point the tissue concentration stays the same irrespective of the soil copper concentrations. Rhoads et al. (1989) found copper concentrations in tomato plants followed a similar pattern plateauing at 34 ug/g. This pattern was not seen in Bioassay #2 where foliar concentrations increased steadily with increasing copper soil concentration (Figure 43).

Figures 44 shows a perfect relationship between total soil copper concentration and foliar copper concentration, indicating that there is increasing copper availability and uptake by the plant with increasing soil copper concentrations. In these bioassays several factors, including nutrient deficiencies, were found to influence growth and complicate the interpretation of the results. The relationship shown in Figures 44 and 45 suggest that the reductions in growth and toxicity symptoms observed in the plants grown in the higher copper contaminated soils can be attributed to copper toxicity.

DPTA and other extractants are often used as better indicators of copper availability than total soil concentrations. In this experiment the extraction of copper with DPTA gave a slightly poorer measure of bioavailability, for the radish, than total soil copper concentration. Therefore, for these soils the total soil copper concentration can be used as a good measure of bioavailability of copper.

The results of Bioassay #1 indicate that pH 6.9 to 7.0 soils, with a copper concentration of 6,438 and 11,405 ug/g, are highly toxic to the vegetables tested. Germination in the 73, 895 and 1511 soils was poor which eliminated the possibility of performing meaningful statistical contrasts. The threshold of injury appears to be between 1852 and 6438 ug/g copper. Had the 1852 ug/g soil not been included, there would have

been a clear pattern of decreasing growth with increasing copper concentration. The good growth in the 1852 ug/g soil, which also had excellent germination, shows that copper is not the only factor affecting growth. A plot of leaf area compared to soil potassium concentrations (Figure 6) shows a strong relationship, which indicates that poor growth in the highly contaminated soils may be linked to potassium deficiencies as well as copper toxicity. The fact the control does not fit this pattern indicates other factors also are important.

The Pearson correlation matrix shows that soil copper concentration is the most important factor affecting the radish leaf area (Table 4). The next most important factors are the cation exchange capacity and calcium concentration. Rhoads et al. (1989) suggest that liming and increasing the tissue calcium concentrations of tomato plants reduces copper toxicity. This may be true generally, since all the soils in the bioassays had high calcium concentrations and the neutral pH of the soil is, to a large extent, a reflection of this high calcium concentration. Specifically, the high correlation between calcium concentration and growth is probably because the low copper soils had higher calcium concentrations rather than an ameliorating influence of the calcium on high copper soils. Daniels and Struckmeyer (1973) report a close association between copper toxicity and iron deficiency. The symptoms of copper toxicity in the bean plants used in their experiment could be ameliorated through the use of EDTA, which increased the iron concentrations in the roots and shoots. Soil iron concentrations show a poor correlation with growth and are, therefore, unlikely to play a major role in the pattern of growth.

Bioassay #2 was designed to overcome the problems of soil variability encountered in Bioassay #1 and to test the response of plants to the most highly contaminated soil sampled around the Burnstein Castings company. Although the subsoil was the same texture and had similar pH to the surface soil, the organic matter content and nutrient status were different. The addition of peat moss and fertilizer helped rectify these problems but they did not completely solve them. The lower organic matter content in the low copper soils may be due to an initial miscalculation or to a decreased rate of organic matter decomposition in the highly copper contaminated soils. Copper effectively reduces decomposition of organic soils and copper sulphate is often recommended as an addition to muck soils to slow their subsidence (Levesque and Mathur 1983).

Fertilizer was added in relatively low concentrations assuming the soils had moderate fertility (Table 3). Soil analysis after the experiment revealed that all the soils were nutritionally poor, or seriously deficient (Table 2). In spite of no apparent difference in soil chemistry between fertilized and unfertilized soils (Table 2) there was a tremendous response in the radish plants to these fertilizer additions. This response was not only in terms of overall growth but in terms of growth patterns with respect to soil copper concentration. Figure 20 of leaf area of fertilized radish plants shows a typical response curve to soil contamination. Growth is consistent up to 1333 ug/g copper, after which there is a drastic decline. The threshold of injury, based on these results, might be considered between 1333 and 2233 ug/g and indicates that copper is the cause of the growth decline. The unfertilized radish plants show quite a different pattern and interpretation (Figure 14). The highest copper contaminated soil shows the greatest leaf area. This area is approximately half that in the fertilized plants, yet it suggests other factors are influencing growth more than copper concentrations. Some fertilizers, such as ammonium-nitrate, can acidify the soil thus increasing the copper availability. However, there was no alteration in the pH of this soil. Why fertilization would reduce growth in the highest copper contaminated soil is not known. Fertilization generally has a beneficial effect. Smith and Bradshaw (1976) found that fertilizers applied at agricultural rates enabled plants to

revegetate metal contaminated sites.

The poor growth of the unfertilized radish plants in the 62, 400 and 750 ug/g copper soil treatments may be due to a combination of phosphorus and potassium deficiency. The plants were stunted and had an anthocyanin pigmentation in the leaves, which is indicative of phosphorus deficiency. Phosphorus concentrations were low but not in the deficiency range in the bioassay soils (Table 2). The subsoil used for the control had the lowest phosphorus concentrations and the 8066 ug/g copper contaminated soil had the highest concentrations. Mixes of these various soils predictably had intermediate values reflecting the ratio of the mix. In alkaline soils reduced availability of phosphorus can be a problem. Wallace and Cha (1989), working with bushbeans, point out that soil liming to pH 8.0 will protect against copper excess but can cause decreased phosphorus uptake. The soil in the bioassays ranged from pH 7.0 where phosphorus is maximally available (Brady 1974) to pH 7.7. The higher pH may have decreased the availability of the phosphorus; however, the most marked phosphorus deficiency symptoms were in the control plants where the pH was 7.0. Potassium was low or deficient in all soils. This undoubtedly affected plant growth.

The relatively good growth of radish plants in the unfertilized 8066 ug/g copper soil suggests that these plants are not suffering from copper toxicity at this concentration (Figure 14 to 16). These figures hide the fact the root systems of these plants, as well as the beans and spinach, were severely stunted. This restricted pattern of rooting did not affect the mortality of seedlings growing in the greenhouse under well watered conditions. Under drought conditions the seedlings in this treatment probably would have died since the zone of rooting was restricted to within 2 cm of the root base.

The beans showed no significant effects due to fertilization or soil copper concentration (Figures 25 to 34). This may be due to large energy reserves in the cotyledons, and the relatively low nutrient requirements of beans. The 3600 ug/g soil tended to show greatest growth in both the fertilized and unfertilized treatments. This response is exactly opposite to the response of the radish plants which did very poorly in the 3600 ug/g soil (Figures 15 to 18 and 20 to 24). The reason for this opposite response is not known but it does highlight the importance of the plant species under consideration when determining levels of toxicity.

The bean root systems in the 3600 and 8066 ug/g copper soil were stunted, yet nodulation was evident in all treatments, except the 8066 ug/g treatment. This indicates the bacterial symbiont, Rhizobium, was able to survive in soils up to 3500 ug/g copper. Hallsworth <u>et</u> <u>al.</u> (1964) found nodulation of <u>Trifolium</u> <u>sp.</u> increased with copper concentrations from 6 to 160 ug/g but decreased at 1600 ug/g. The nodules at the higher copper concentration were heavier and with a higher nitrogen concentration than those in the lower copper soils. The lack of nodulation in the 8066 ug/g soil copper treatment may be due to the high copper concentrations in the soil or to the fact the root structure in this treatment was severely altered.

The pattern of response of the spinach plants to the various soil treatments was similar for fertilized and unfertilized soils (Figures 35 to 42). This was not a lack of response to the fertilizer, since the fertilized plants were more than twice as large as the unfertilized plants. The relatively poor growth in the 63 and 405 ug/g treatments was probably attributable to nutrient deficiencies. This crop received a much higher rate of fertilization than the beans or radishes but it also requires a higher rate of fertilization (Table 3). Figures 37 and 41 show a sharp decrease in leaf area between the 1333 and 2233 ug/g soil copper treatments. Other growth measures such as plant height and dry

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Table 1: Bioassay #1 soil properties

Site	Total Copper	Cu*	pH	CEC	Organic matter (%)	P	K	Mg	Ca	Zn	Mn	Fe	B
67	73	70	7.2	24	2.8	23	64	112	4290	7.1	33.2	16	.3
78	346	200	7.1	25	7	21	141	424	3890	35.9	41.2	30	1.3
77/78	895	400	7	25	7	18	127	405	3940	47.1	39.5	20	.9
77	1511	600	7.1	18	7	14	97	41	3171	50.4	38.8	18	.8
30	1852	700	7.0	19	6.8	30	164	300	2967	73	49	9	.7
67/75	6438	1100	6.9	16	5.2	35	78	172	2656	58.9	47.1	3	.6
75	11405	1300	7	13	6.4	40	85	175	2034	80.3	37.5	20	1

+ DPTA extractable copper

Concentrations of all metals in ug/ g

Table 2: Bioassay #2 soil properties

Total Copper	fertilized	Cu*	pH	CEC	Organic matter (%)	P	K	Mg	Ca	Zn	Mn	Fe	B
62	N	10	7.1	24	4.2	5	37	188	4210	2	28.5	17	1
403	Y	100	7.5	23	4.7	6	37	146	4060	7.4	41.6	15	.8
403	N	100	7.7	22	4.5	5	26	156	3920	7.1	42.6	15	.8
753	Y	300	7.7	19	3.9	5	24	143	3310	11.2	46.4	14	.6
753	N	200	7.7	24	4.5	6	25	210	4240	11.4	45.8	13	.9
1333	Y	300	7.6	22	4.6	7	30	187	3920	14.7	54.9	12	.8
1333	N	400	7.6	23	4.3	8	26	200	3940	17	52.1	12	.8
2233	Y	700	7.5	22	5.1	12	30	203	3810	26.1	54.2	8	.7
2233	N	600	7.5	19	4.5	12	28	175	3203	23.6	52.6	10	.7
3600	Y	700	7.4	19	5.2	20	32	200	3296	29.3	53.4	4	.8
3600	N	700	7.4	22	5.7	21	37	194	3910	29.7	52.9	1	1
8066	Y	1000	7.3	17	5.8	24	44	204	2896	44.3	63	1	.9
8066	N	1100	7.0	17	6.2	30	71	225	2823	54.5	52.7	2	1.2

* DPTA extractable copper

Concentrations of all metals in ug/ g

Table 3: The Ontario Ministry of Agriculture and Food recommended fertilizer applications for a medium fertile mineral soil and the amount of fertilizer applied per pot in Bioassay #2.

		OMAF recommended rate	rate per pot
Radish var. Cherry belle	N	60 kg/ha	1.99×10^{-1} g
	P	40 kg/ha	1.33×10^{-1} g
	K	50 kg/ha	1.66×10^{-1} g
Spinach var. Longstanding bloomsdale	N	100 kg/ha	3.32×10^{-1} g
	P	140 kg/ha	4.65×10^{-1} g
	K	200 kg/ha	6.64×10^{-1} g

Note: Bean plants were grown in the same soil as the radish plants

Table 4: Pearson correlation matrix of Bioassay #1 radish leaf area and soil properties

	Leaf area
Total copper	**-0.807**
CEC	**-0.779**
Organic matter	**-0.222**
Phosphorus	**-0.518**
Potassium	**0.427**
Magnesium	**0.314**
Calcium	**0.785**
Zinc	**-0.617**
Manganese	**-0.125**
Iron	**0.279**

Figure 1:

Soil Collection Sites in the Vicinity of Burnstein Castings - March 1988 through August 1989

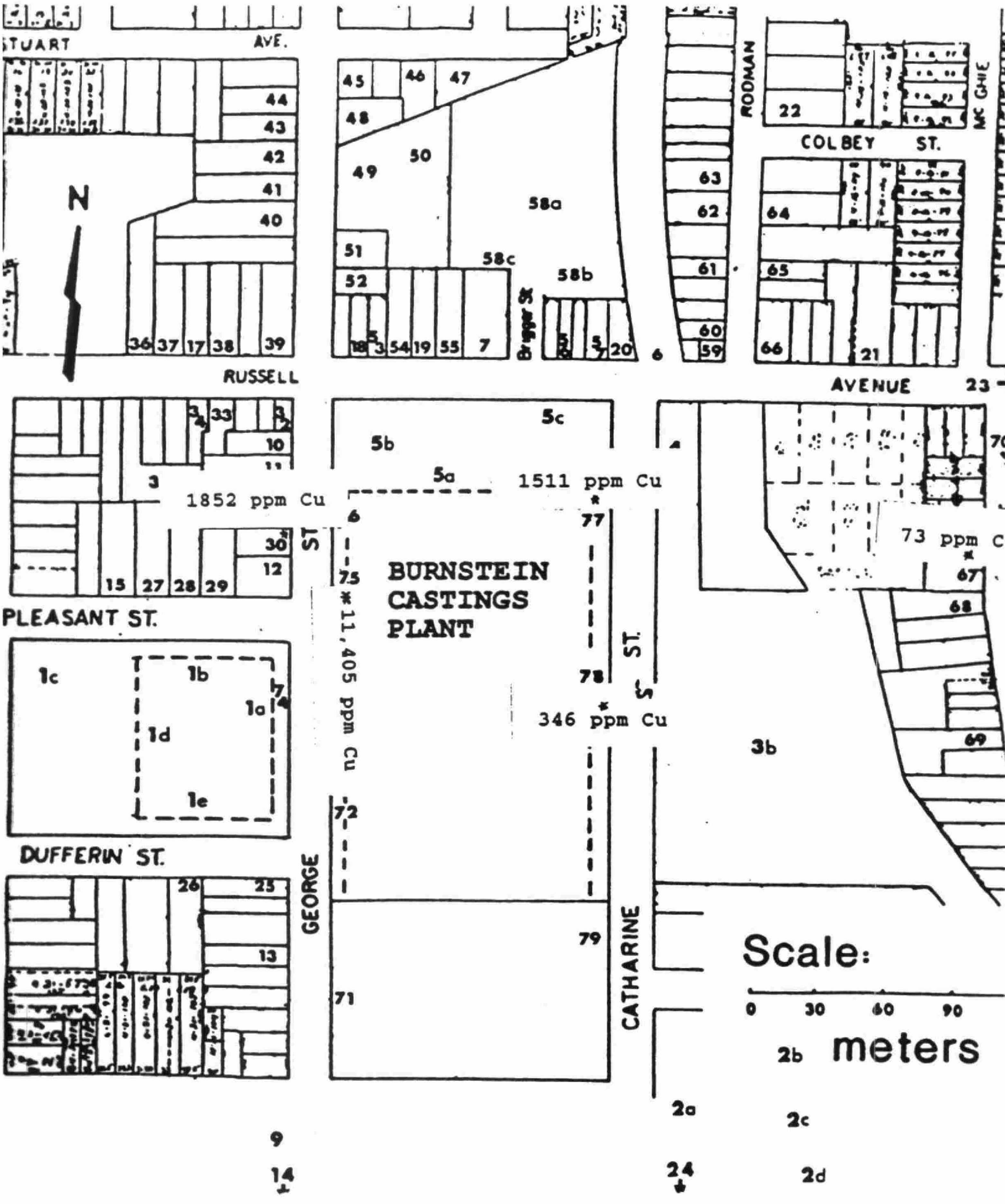


Figure 2: Leaf area of "Cherry Belle" radish plants grown for 54 days in soils collected in tne vicinity of the Burnstein castings plant

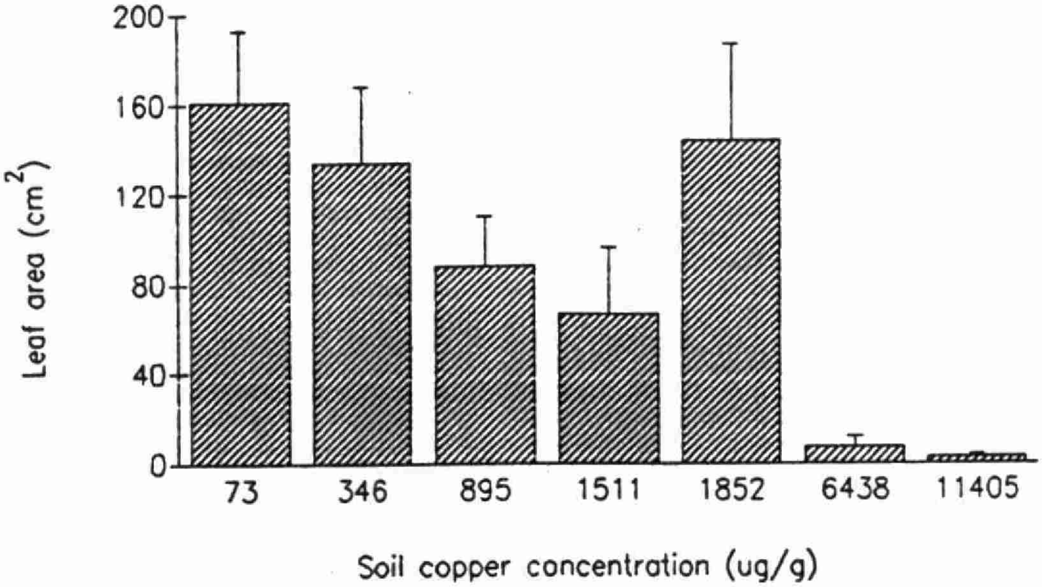


Figure 3: Shoot dry weight of "Cherry Belle" radish plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

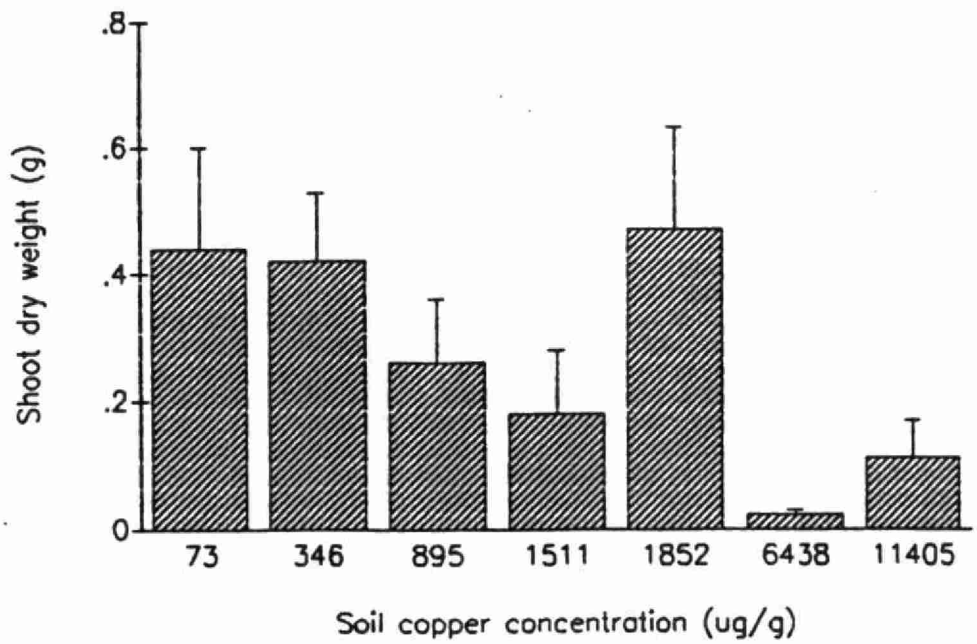


Figure 4: Hypocotyl diameter of "Cherry Belle" radish plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

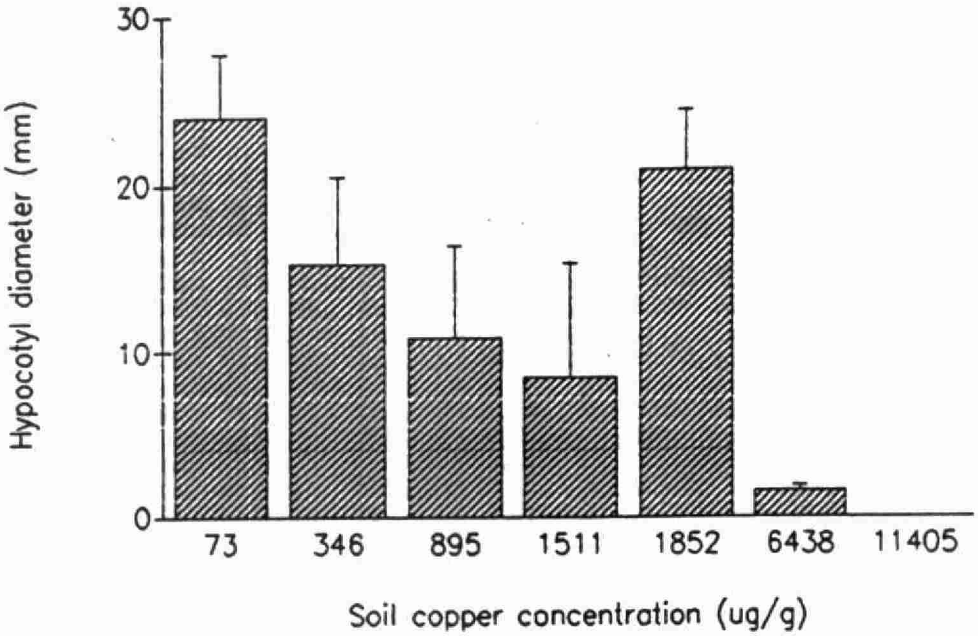


Figure 5: Hypocotyl dry weight of "Cherry Belle" radish plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

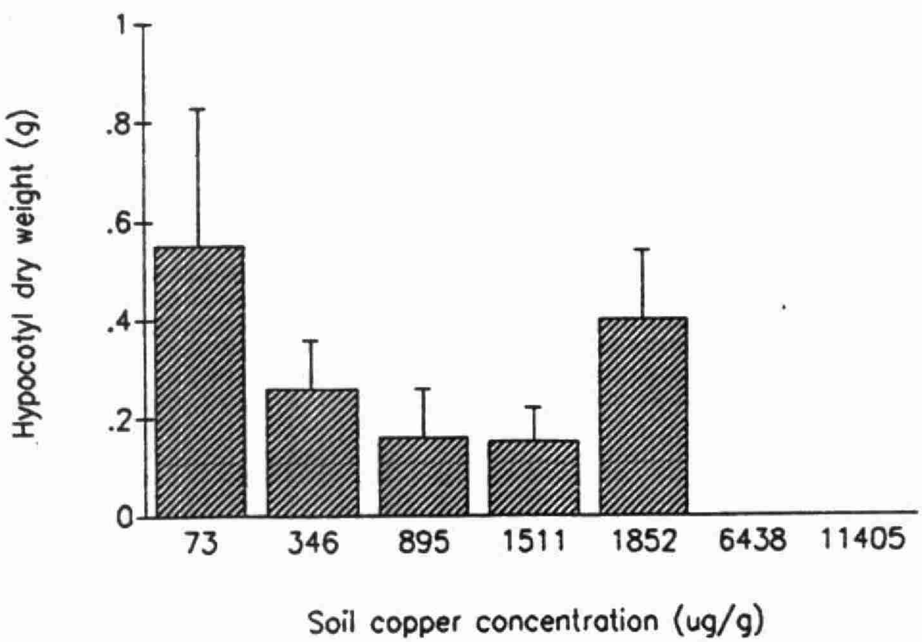
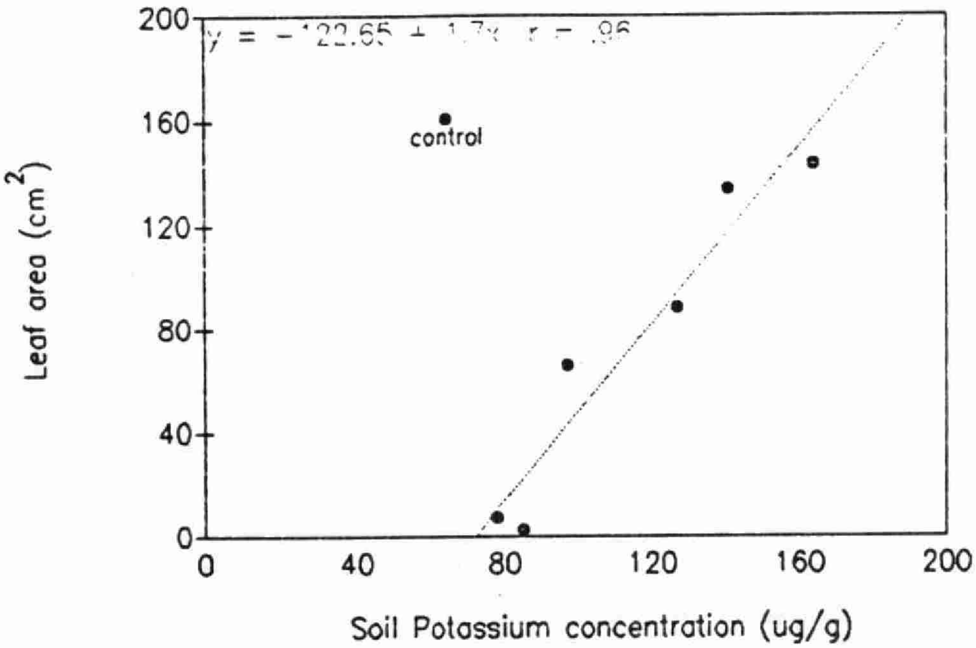


Figure 6: Relationship between radish leaf area and soil potassium concentration from Bioassay #1



N.B. The control was not included in the calculation of the regression equation

Figure 7: Height of "Tendergreen stringless" bean plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

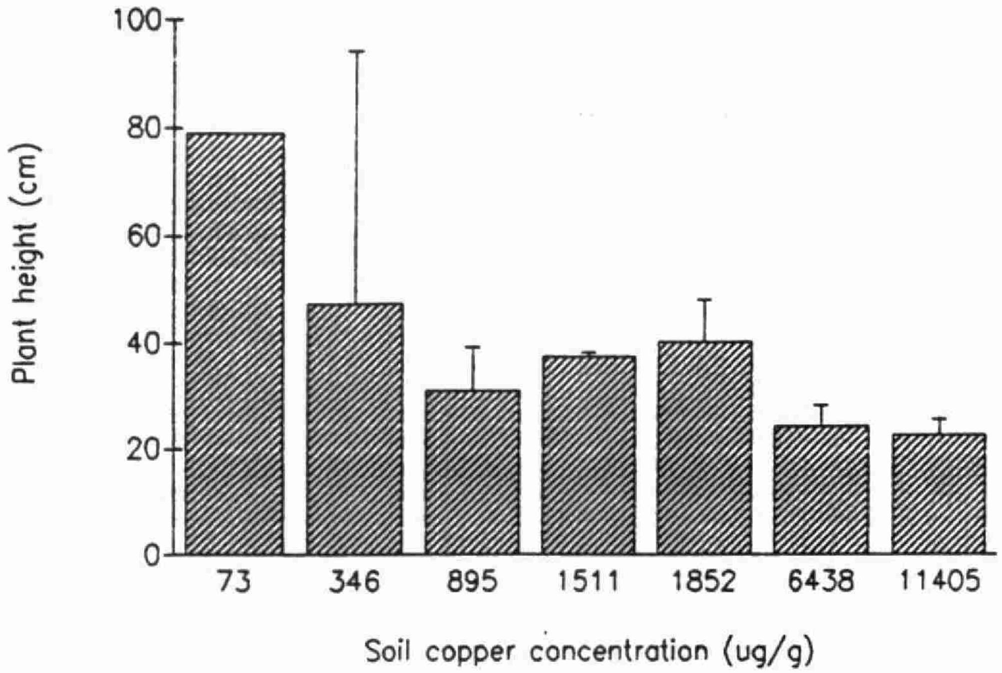


Figure 8: Leaf area of "Tendergreen stringless" bean plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

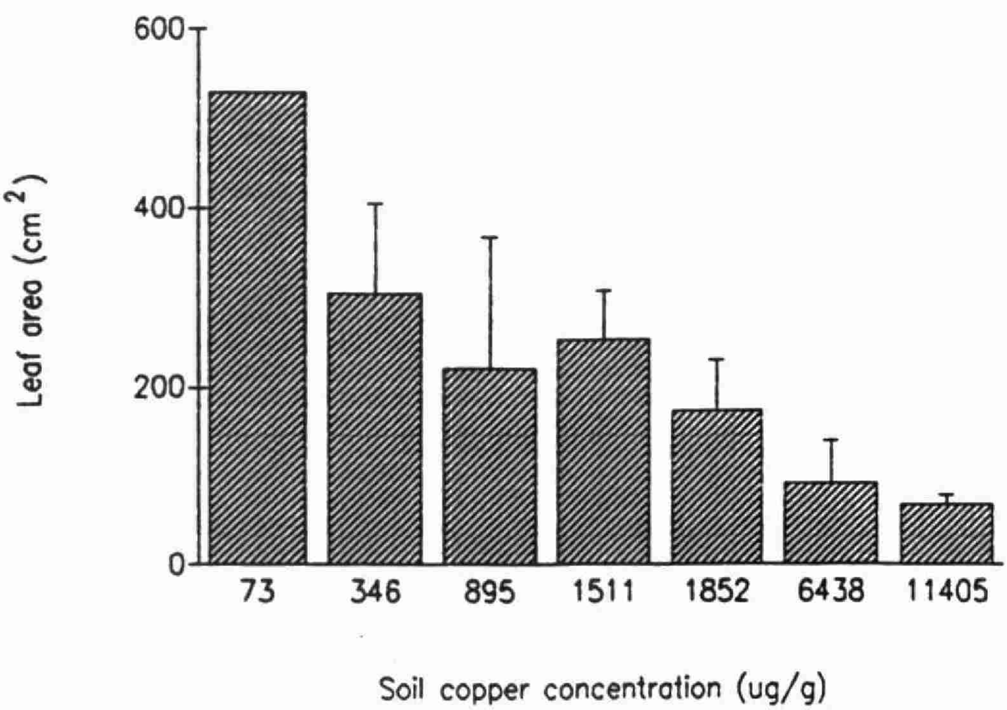


Figure 9: Shoot dry weight of "Tendergreen stringless" bean plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

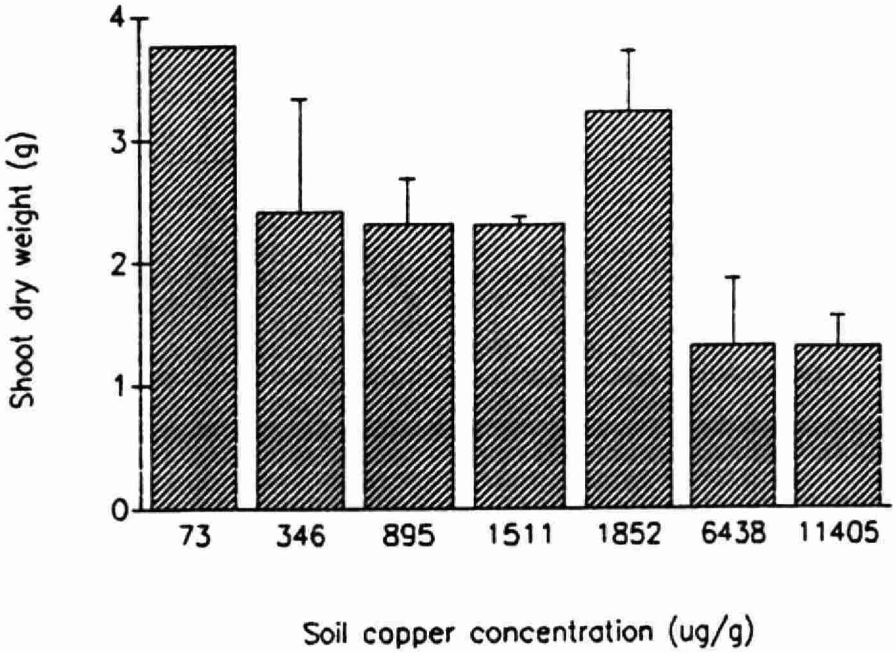


Figure 10: Root dry weight of "Tendergreen stringless" bean plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

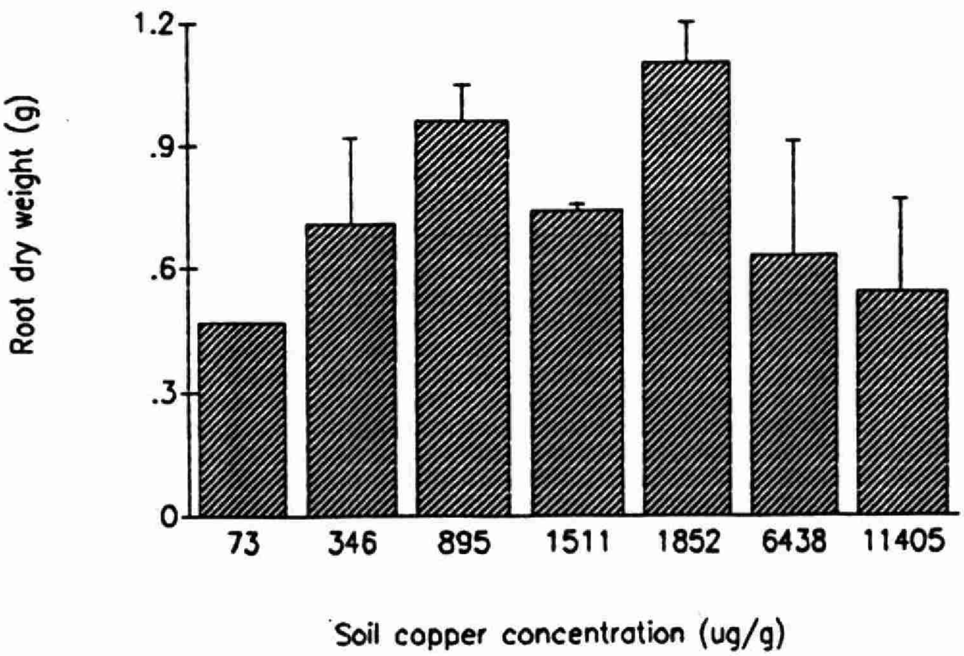


Figure 11: Average number of pods of "Tendergreen stringless" bean plants grown for 54 days in soils collected in the vicinity of the Burnstein castings plant

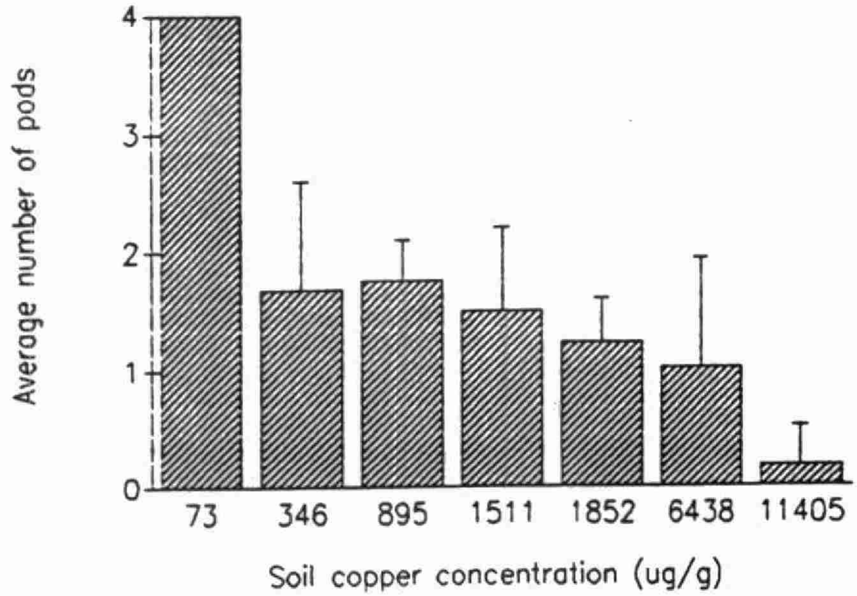


Figure 12: Copper concentration in the tissue of "Cherry belle" radish plants grown in copper contaminated soil collected in the vicinity of Burnstein castings: Bioassay#1

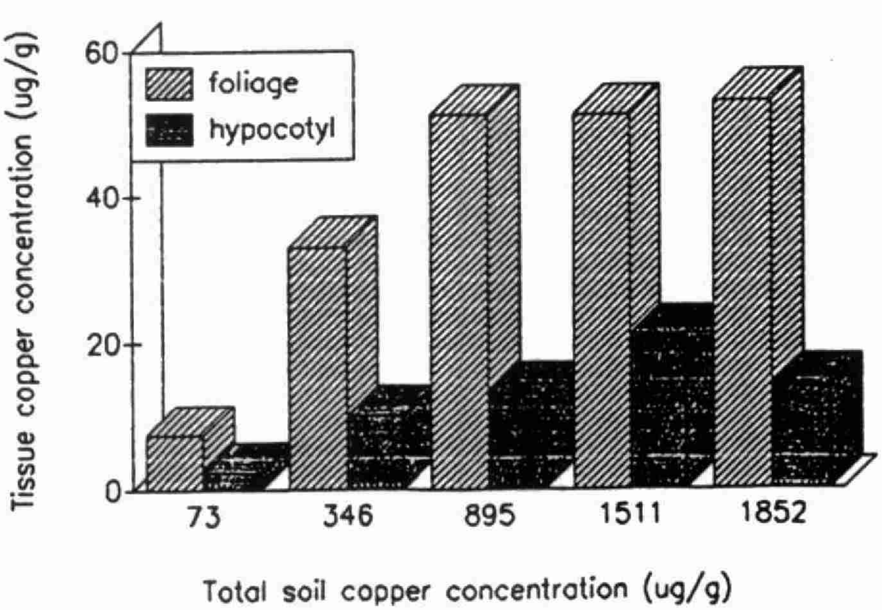
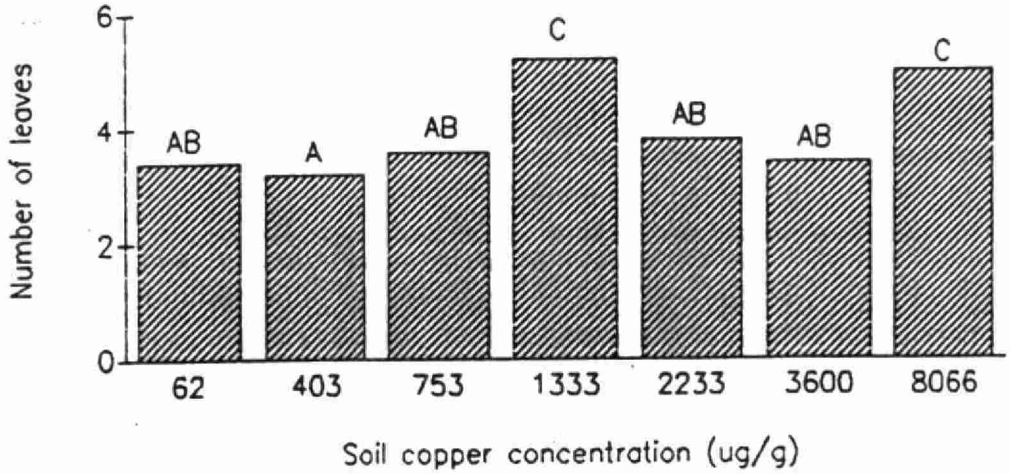


Figure 13: Number of leaves of "Cherry Bell" radish plants grown for 39 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



columns with the same letter are not significantly different (p> 0.05)

Figure 14: Leaf area of "Cherry Bell" radish plants grown for 39 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines

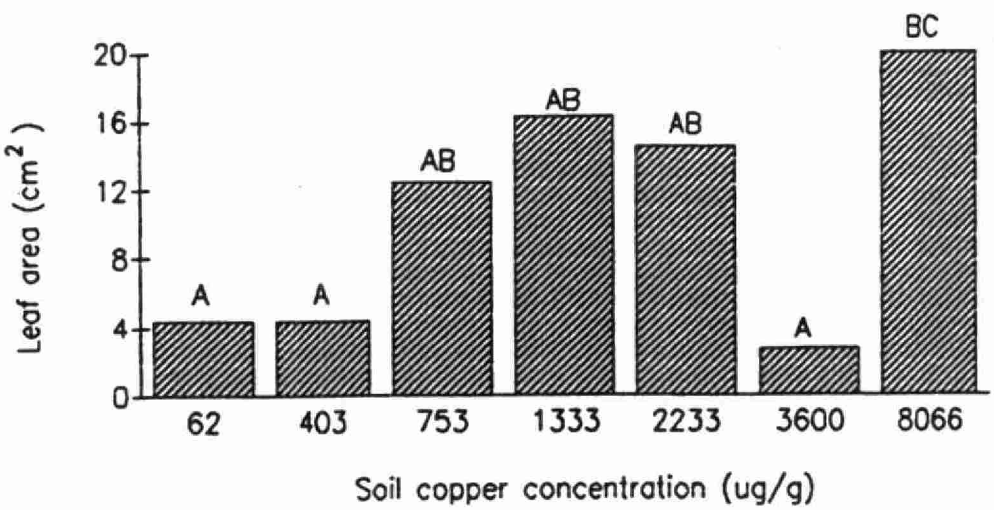


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Figure 15: Shoot fresh weight of "Cherry Bell" radish plants grown for 39 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines

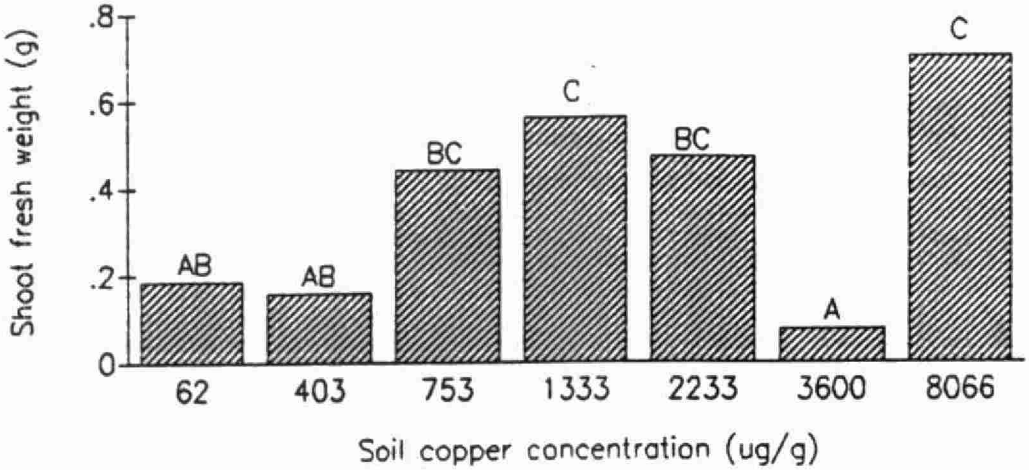

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Figure 16: Shoot dry weight of "Cherry Bell" radish plants grown for 39 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines

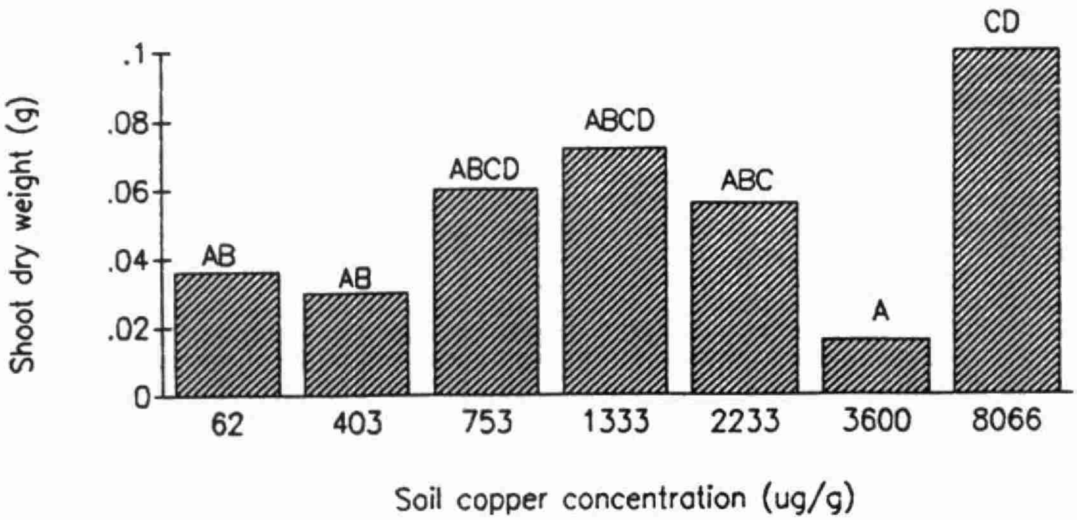

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Figure 17: Hypocotyl diameter of "Cherry Bell" radish plants grown for 39 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines

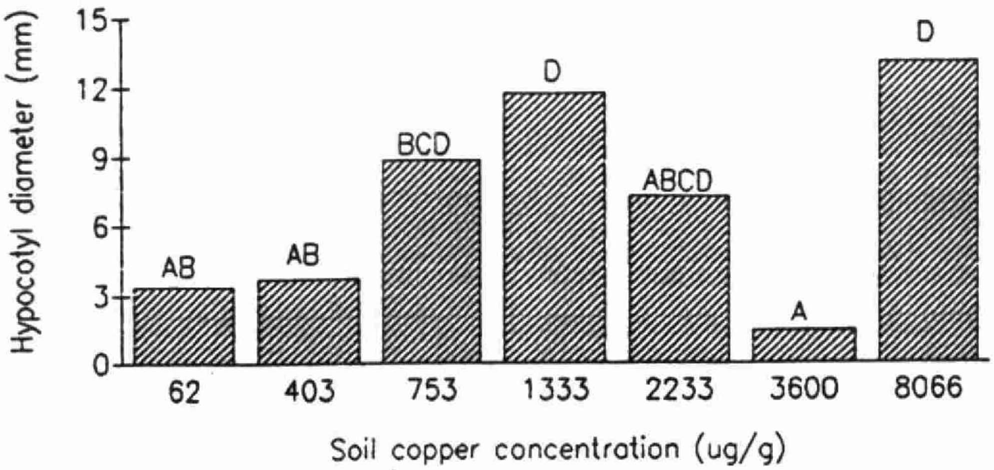

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Figure 18: Hypocotyl fresh weight of "Cherry Bell" radish plants grown for 39 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines

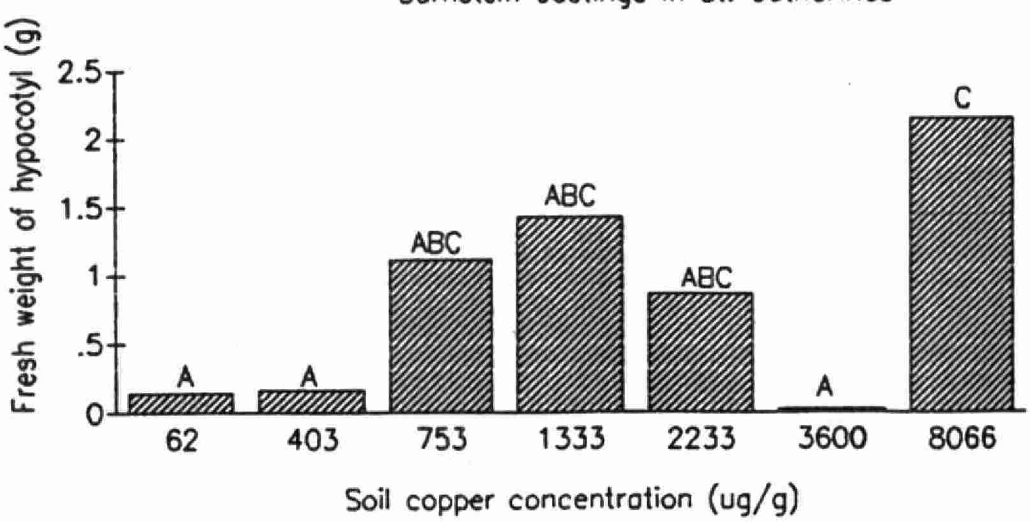

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Figure 19: Number of leaves of "Cherry Bell" radish plants grown for 39 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines

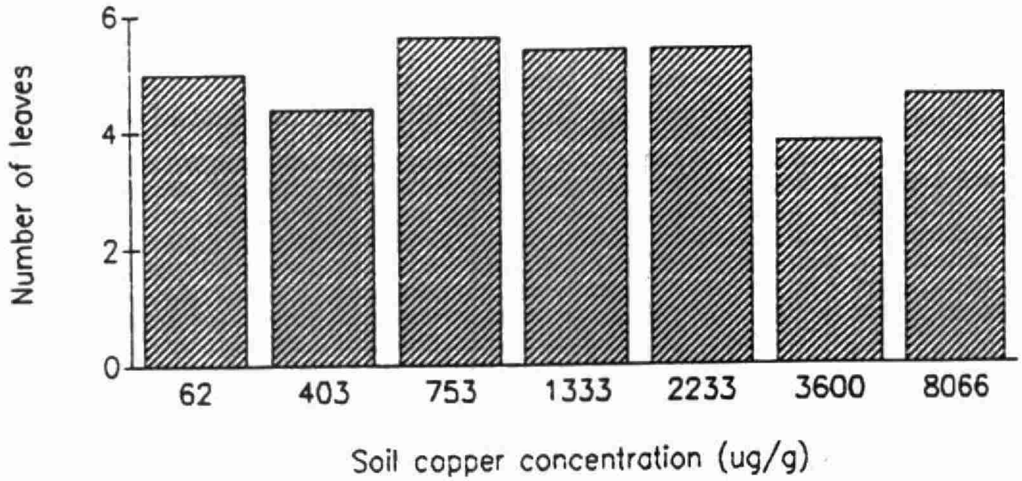

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Figure 20: Leaf area of "Cherry Bell" radish plants grown for 39 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines

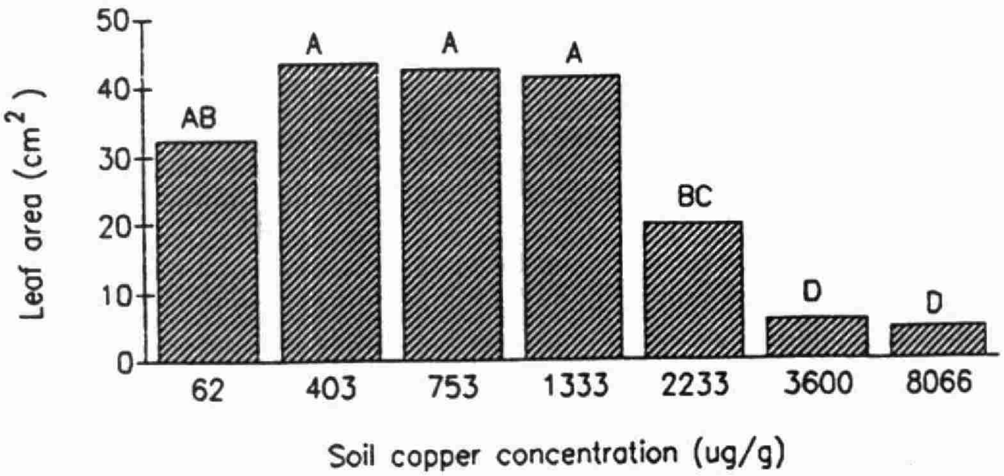

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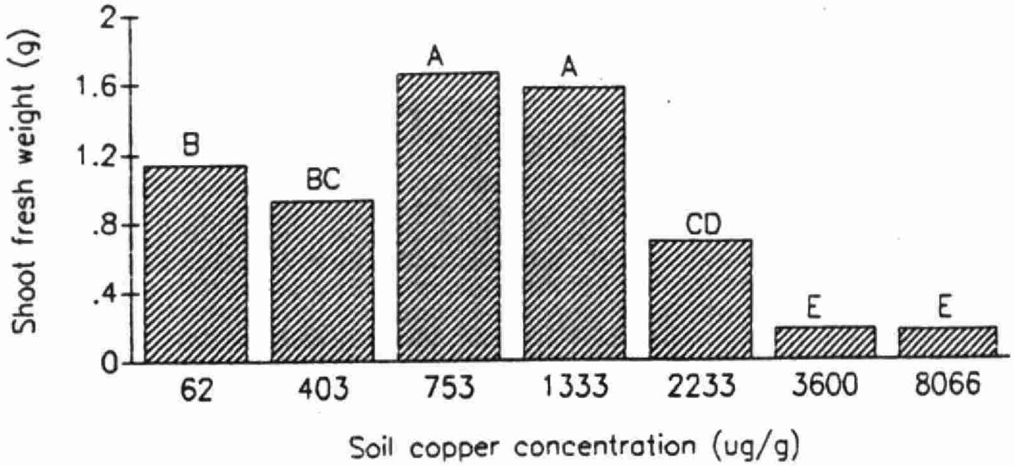
Figure 21: Shoot fresh weight of "Cherry Bell" radish plants grown for 39 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



columns with the same letter are not significantly different ($p > 0.05$)

Figure 22: Shoot dry weight of "Cherry Bell" radish plants grown for 39 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines

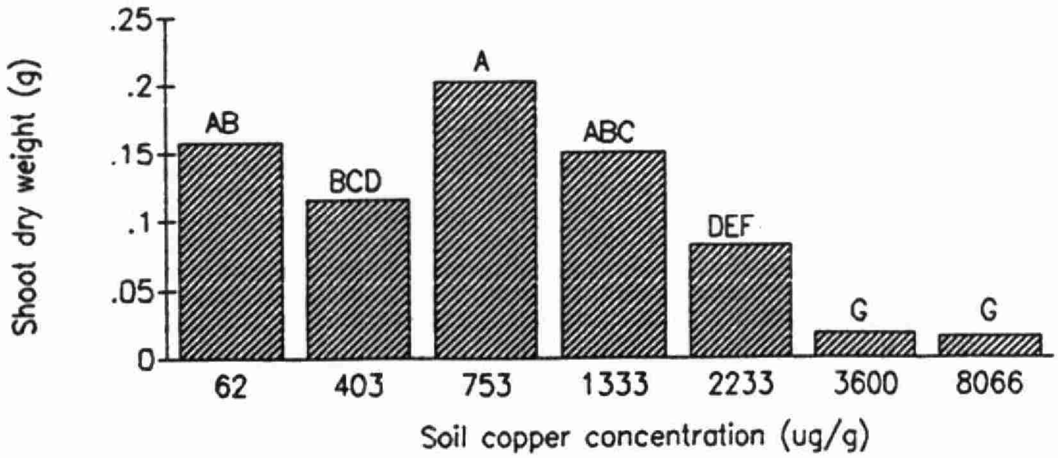


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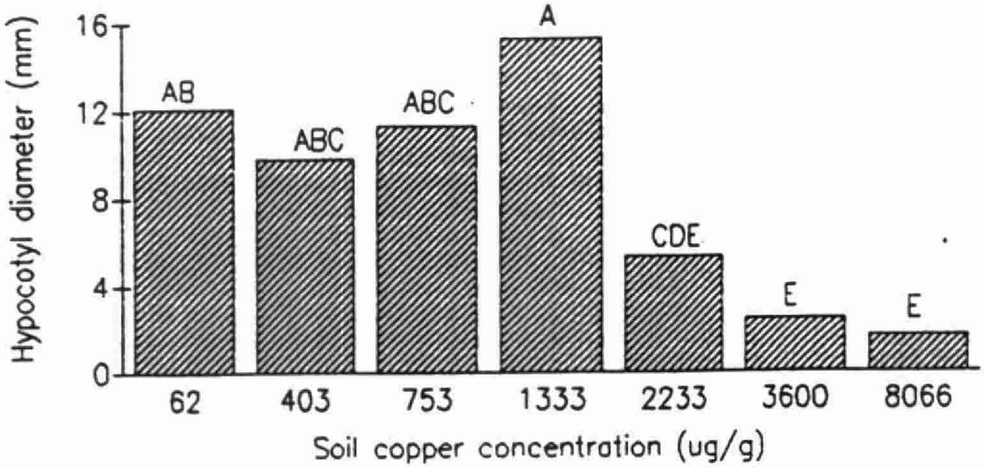
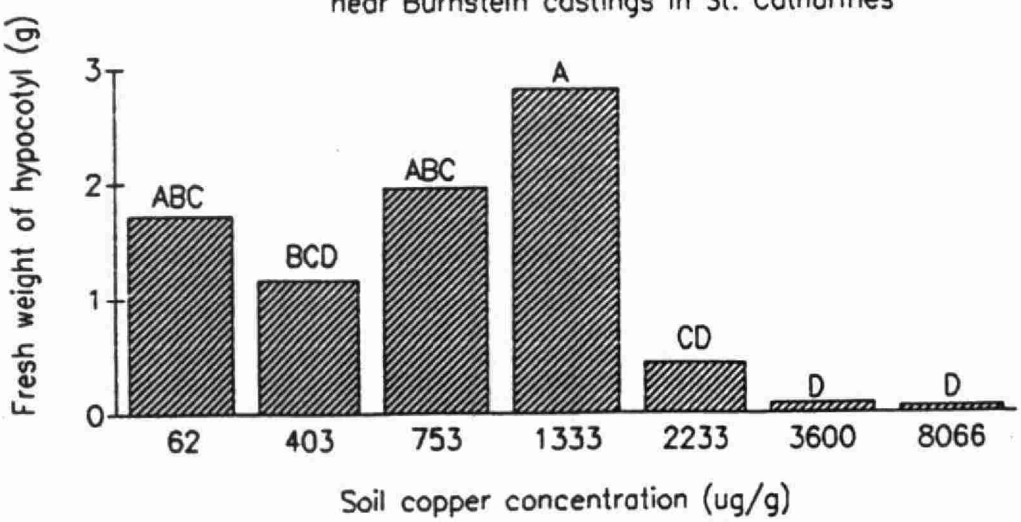
Figure 23: Hypocotyl diameter of "Cherry Bell" radish plants grown for 39 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



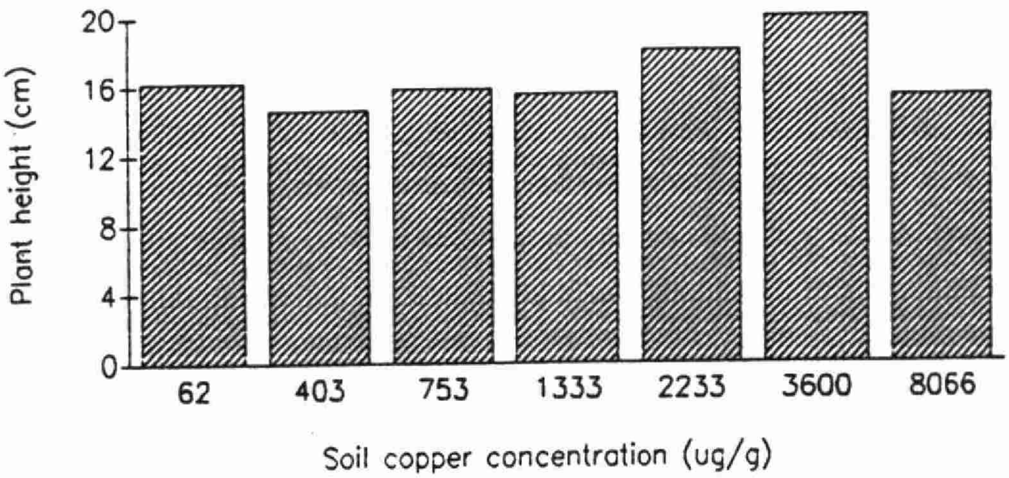
columns with the same letter are not significantly different ($p > 0.05$)

Figure 24: Fresh weight of hypocotyls of "Cherry Bell" radish plants grown for 39 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



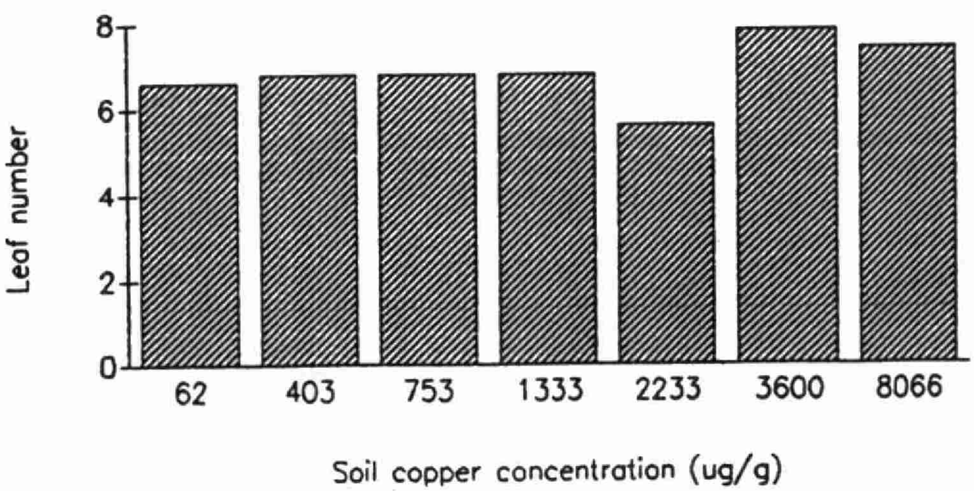
columns with the same letter are not significantly different ($p > 0.05$)

Figure 25: Height of "Tendergreen Stringless" bean plants grown for 40 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



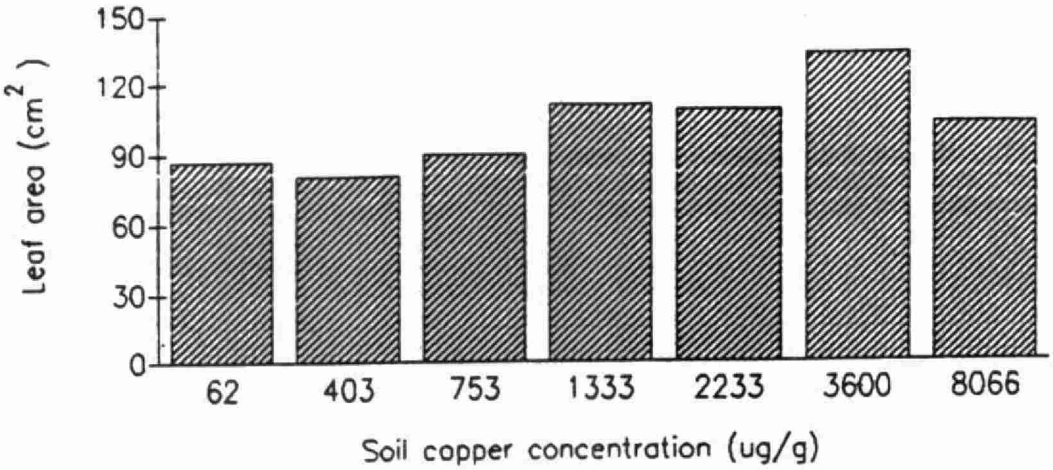
columns are not significantly different ($p>0.05$)

Figure 26: Average number of leaves of "Tendergreen Stringless" bean plants grown for 40 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



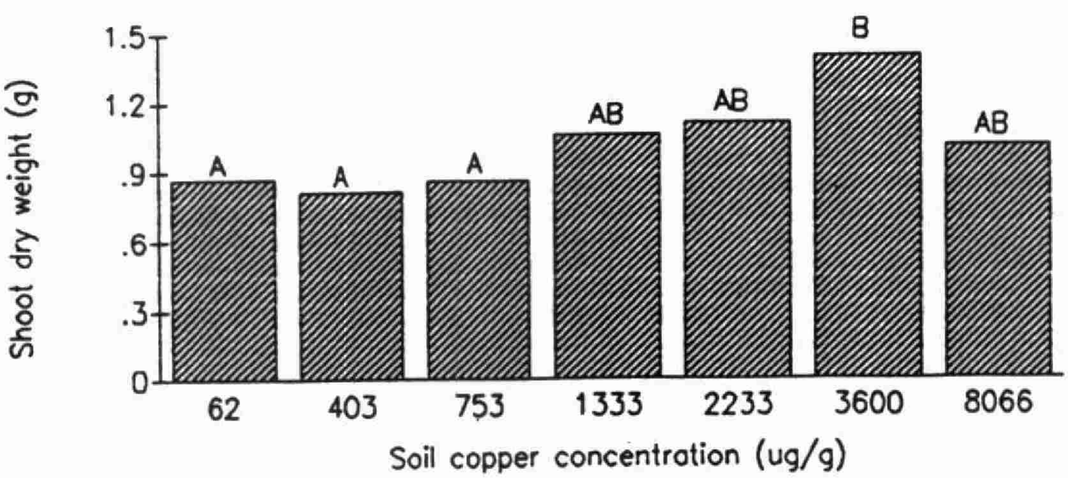
columns are not significantly different ($p>0.05$)

Figure 27: Leaf area of "Tendergreen Stringless" bean plants grown for 40 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



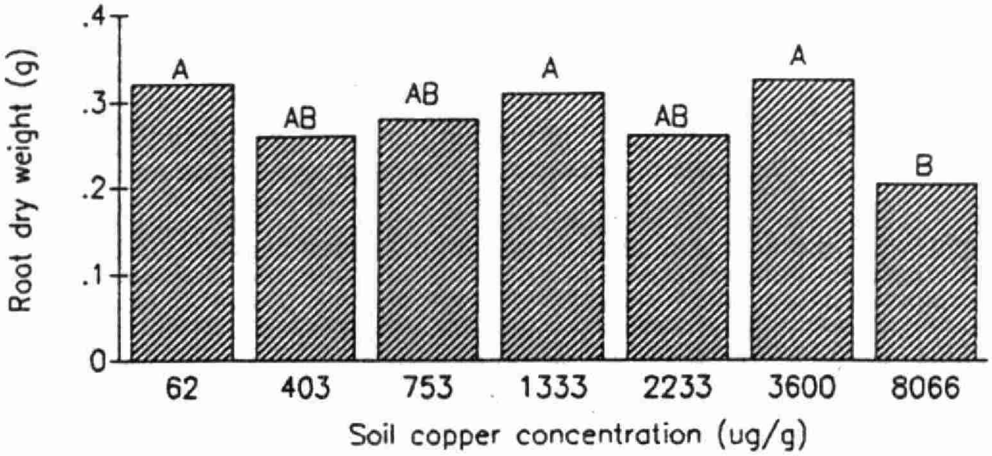
columns are not significantly different (p>0.05)

Figure 28: Shoot dry weight of "Tendergreen Stringless" bean plants grown for 40 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



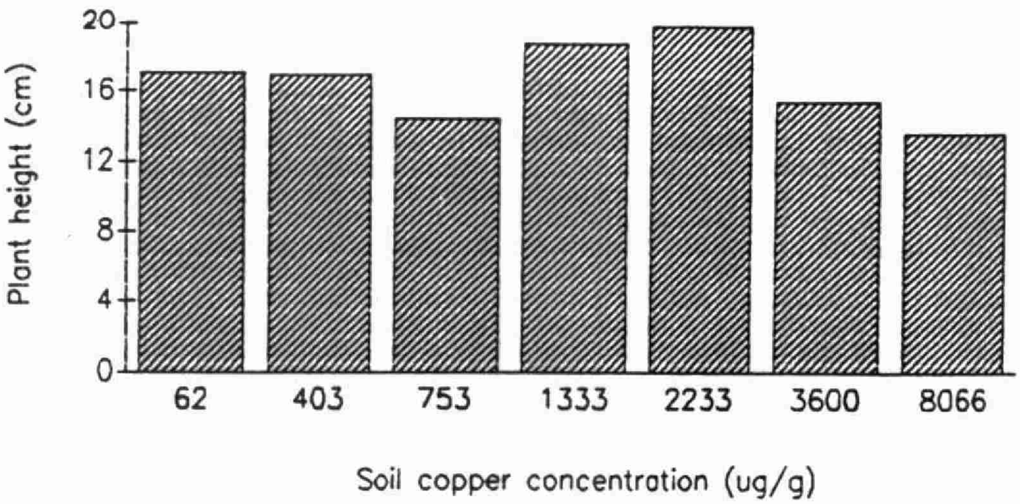
columns with the same letter are not significantly different (p> 0.05)

Figure 29: Root dry weight of "Tendergreen Stringless" bean plants grown for 40 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



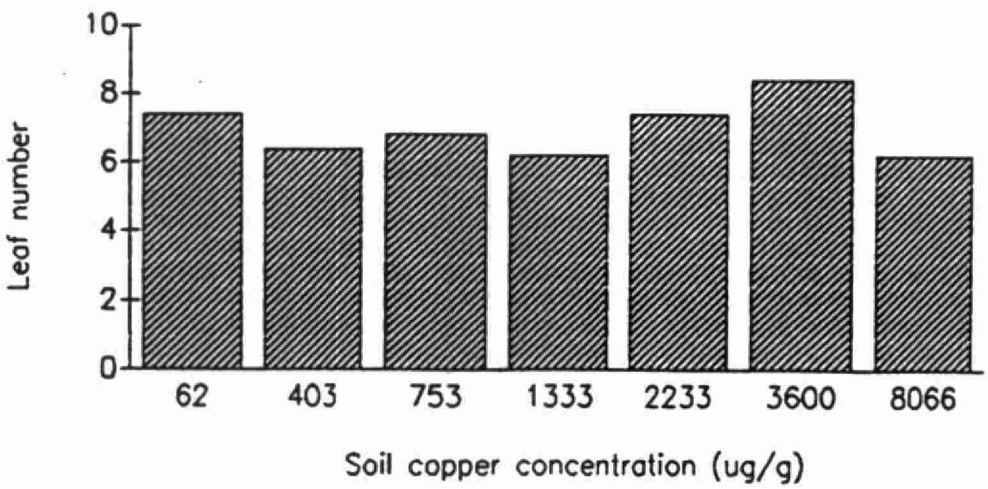
columns with the same letter are not significantly different (p> 0.05)

Figure 30: Height of "Tendergreen Stringless" bean plants grown for 40 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



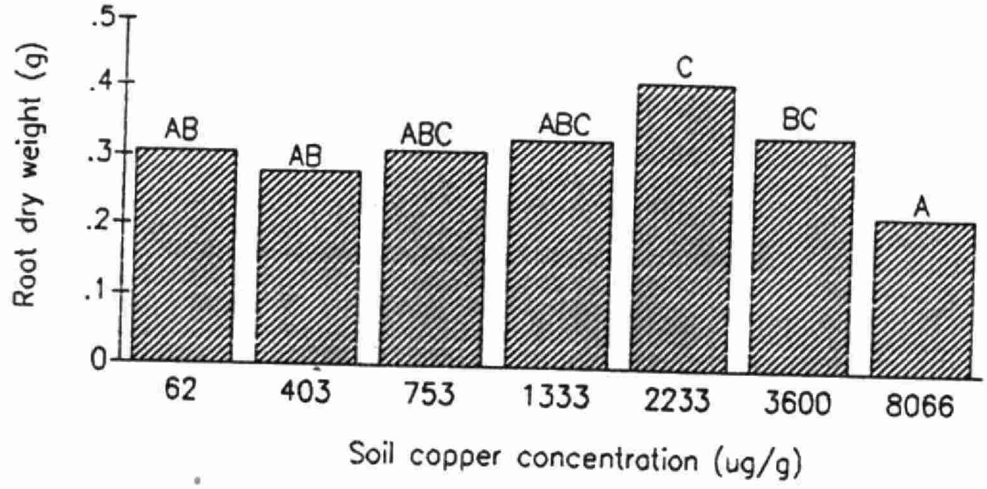
columns are not significantly different (p> 0.05)

Figure 31: Leaf area of "Tendergreen Stringless" bean plants grown for 40 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



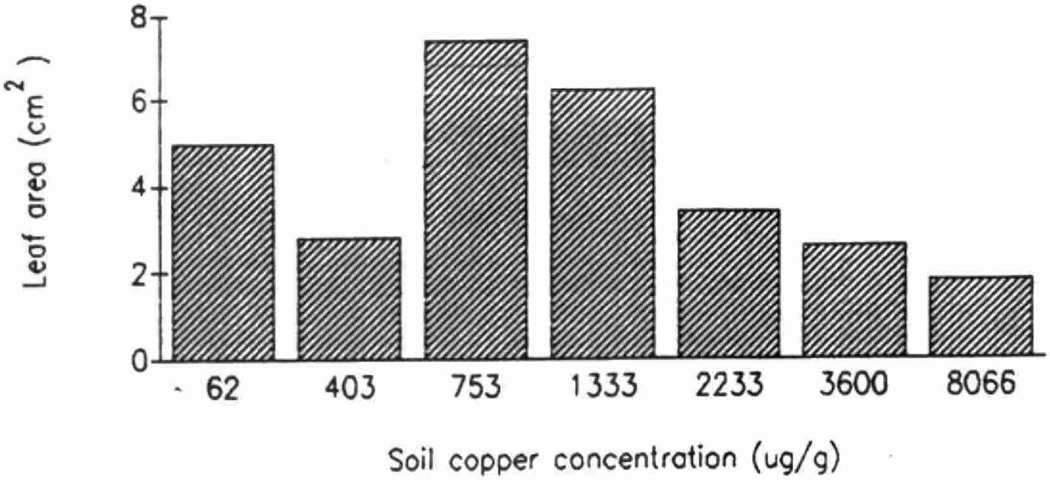
columns are not significantly different (p> 0.05)

Figure 34: Root dry weight of "Tendergreen Stringless" bean plants grown for 40 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



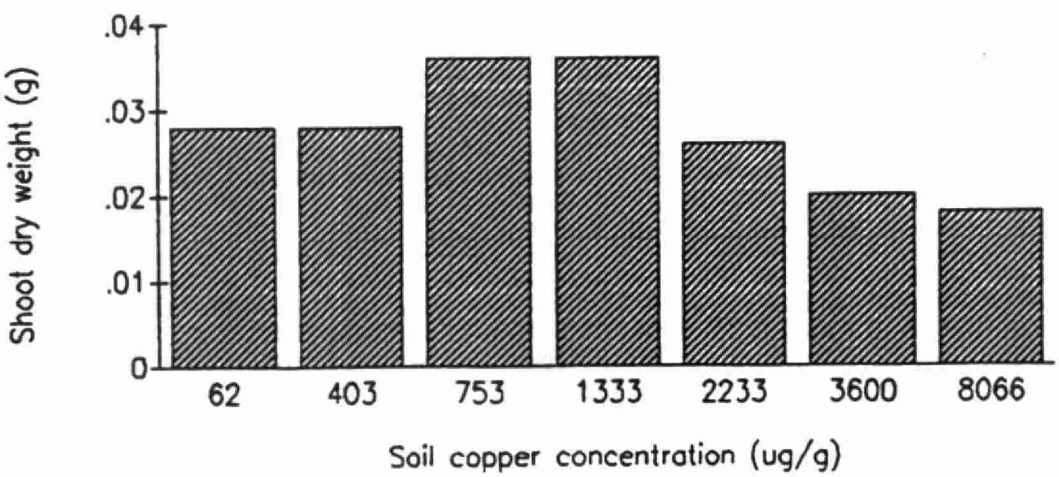
columns with the same letter are not significantly different (p> 0.05)

Figure 37: Leaf area of "Long Standing Bloomsdale" spinach plants grown for 30 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



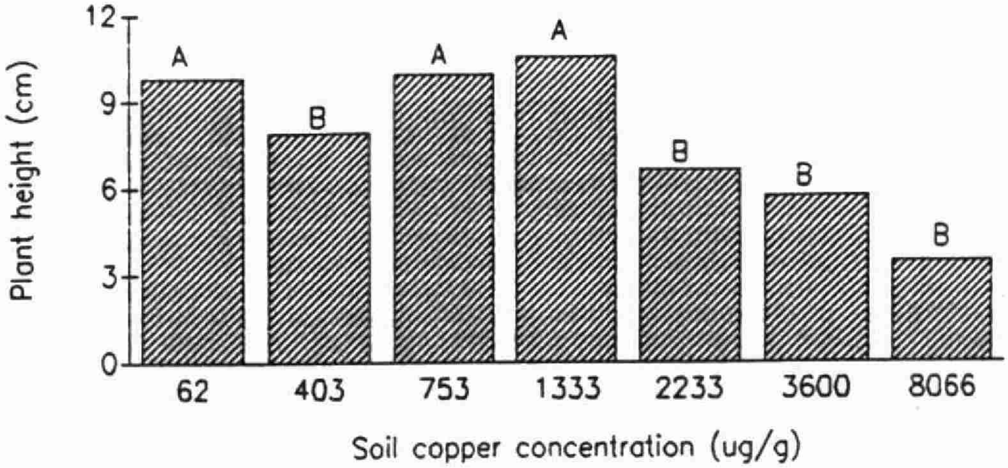
columns are not significantly different ($p > 0.05$)

Figure 38: Shoot dry weight of "Long Standing Bloomsdale" spinach plants grown for 30 days in unfertilized copper contaminated soil collected near Burnstein castings in St. Catharines



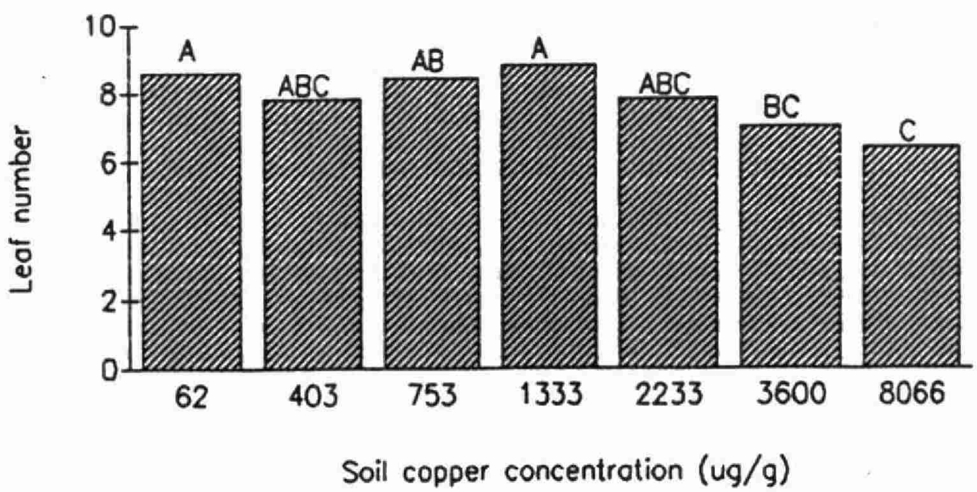
columns are not significantly different ($p > 0.05$)

Figure 39: Height of "Long Standing Bloomsdale" spinach plants grown for 30 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



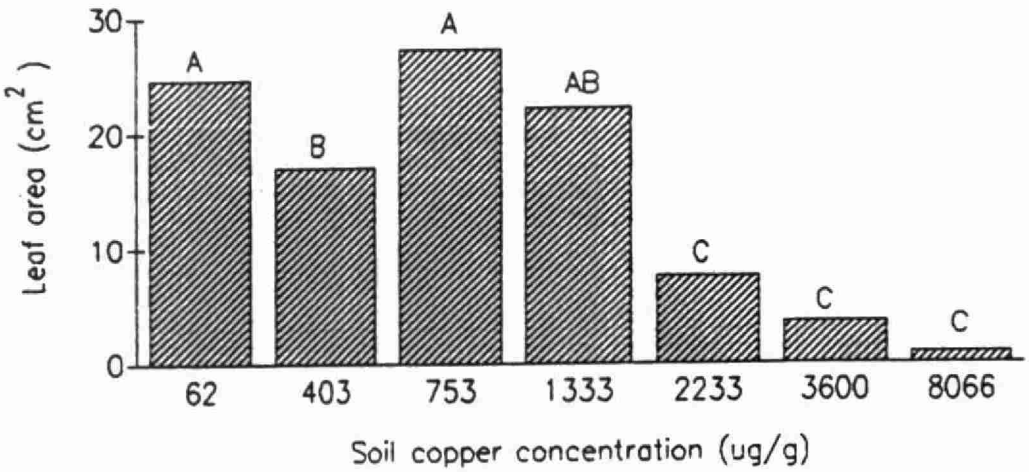
columns with the same letter are not significantly different ($p < 0.05$)

Figure 40: Average number of leaves on "Long Standing Bloomsdale" spinach plants grown for 30 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



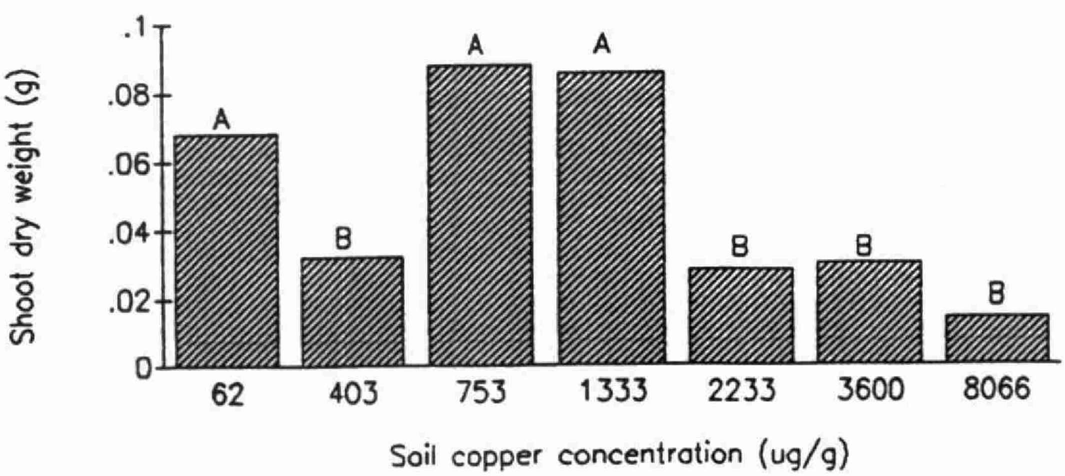
columns with the same letter are not significantly different ($p < 0.05$)

Figure 41: Leaf area of "Long Standing Bloomsdale" spinach plants grown for 30 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



columns with the same letter are not significantly different ($p < 0.05$)

Figure 42: Shoot dry weight of "Long Standing Bloomsdale" spinach plants grown for 30 days in fertilized copper contaminated soil collected near Burnstein castings in St. Catharines



columns with the same letter are not significantly different ($p < 0.05$)

Figure 43: Copper concentration in the tissue of "Cherry belle" radish plants grown in copper contaminated soil collected in the vicinity of Burnstein castings: Bioassay #2

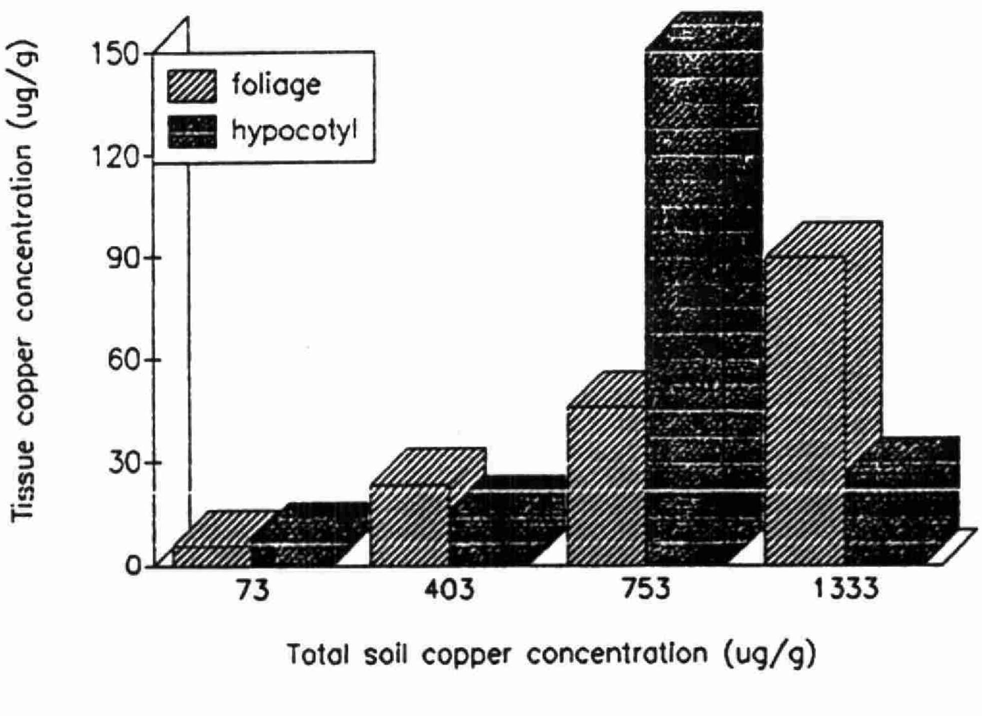


Figure 44: Comparison of radish foliar tissue copper concentration with total soil copper concentration: Bioassay #2

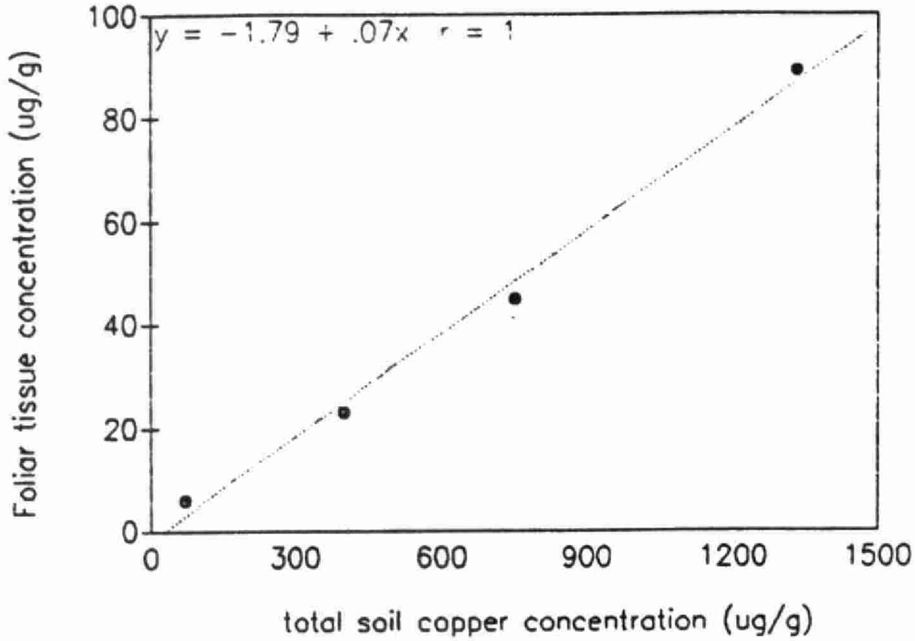


Figure 45: Comparison of radish foliar tissue copper concentration with soil DPTA extractable copper concentration: Bioassay #2

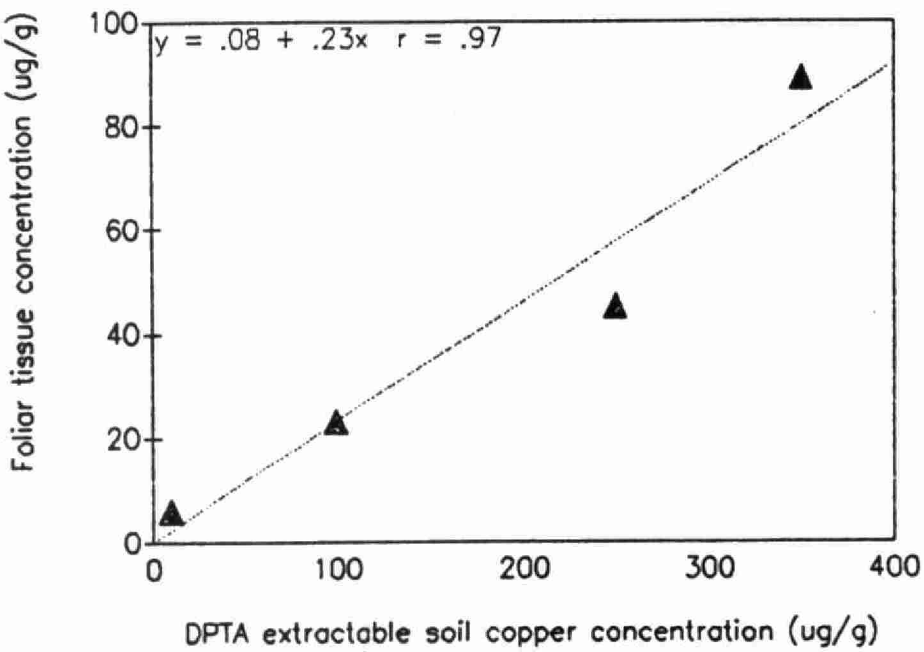


Figure 46: The relationship between foliar copper concentration and shoot dry weight of "Cherry belle" radish plants from Bioassay #1

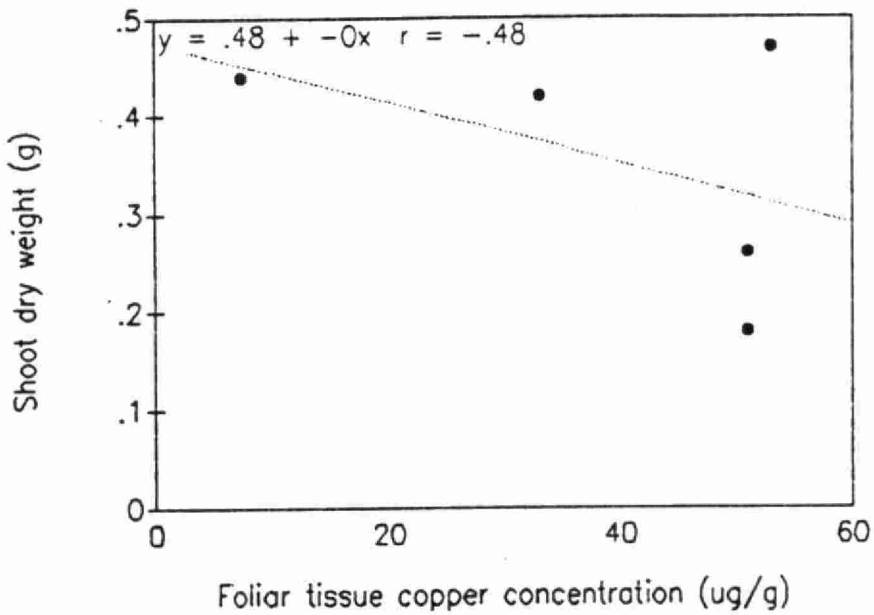
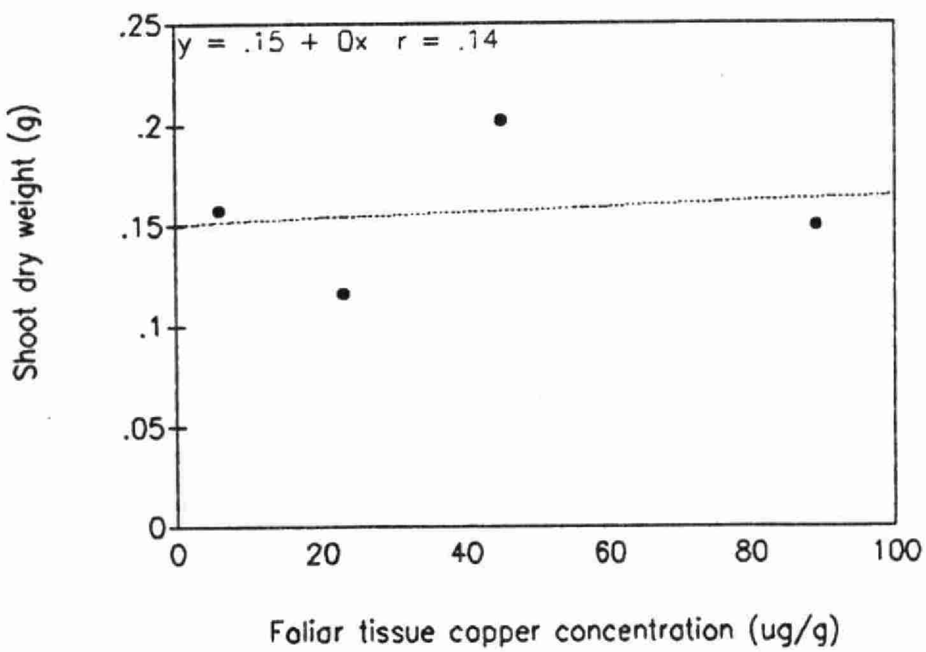


Figure 47: The relationship between foliar copper concentration and shoot dry weight of "Cherry belle" radish plants from Bioassay #2



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